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# REPORT

OF THE

# BOARD OF ENGINEERS ON DEEP WATERWAYS

BETWEEN THE

## GREAT LAKES AND THE ATLANTIC TIDE WATERS.

---

IN TWO PARTS, WITH ATLAS.

PART I.

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WAR DEPARTMENT,
*Washington, December 2, 1900.*

SIR: In connection with Department letter of December 18, 1899, transmitting a preliminary report of the United States Board of Engineers on Deep Waterways, I have the honor to transmit herewith the said Board's complete report upon the subject of deep waterways and routes thereof between the Great Lakes and the Atlantic tide waters, as contemplated by the provisions of the sundry civil act of June 4, 1897.

Very respectfully,

ELIHU ROOT,
*Secretary of War.*

The SPEAKER OF THE HOUSE OF REPRESENTATIVES.

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# REPORT

OF THE

# BOARD OF ENGINEERS ON DEEP WATERWAYS.

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UNITED STATES BOARD OF ENGINEERS
ON DEEP WATERWAYS,
*34 West Congress Street, Detroit, Mich., June 30, 1900.*

SIR: The Board of Engineers designated and appointed by the President, in conformity with the provisions of the sundry civil act of June 4, 1897, to make surveys and examinations of deep waterways and the routes thereof between the Great Lakes and the Atlantic tide waters, has the honor to submit the following report:

The letter constituting the Board is as follows:

WAR DEPARTMENT, *Washington, July 28, 1897.*

Under a provision in the act of Congress making appropriations for sundry civil expenses of the Government for the year ending June 30, 1898, and for other purposes, approved June 4, 1897, Major Charles W. Raymond, Corps of Engineers, United States Army, Alfred Noble, and George Y. Wisner are designated and appointed by the President as a Board of Engineers to make "surveys and examinations (including estimate of cost) of deep waterways and the routes thereof between the Great Lakes and the Atlantic tide waters, as recommended by the report of the Deep Waterways Commission," as required by the said act.

R. A. ALGER, *Secretary of War.*

The provisions of the sundry civil act of June 4, 1897, which authorize the formation and define the duties of the Board are as follows:

DEEP WATERWAYS COMMISSION: For surveys and examinations (including estimate of cost) of deep waterways and the routes thereof between the Great Lakes and the Atlantic tide waters, as recommended by the report of the Deep Waterways Commission transmitted by the President to Congress January 18, 1897, one hundred and fifty thousand dollars. Such examinations and surveys shall be made by a Board of three engineers, to be designated by the President, one of whom may be detailed from the Engineer Corps of the Army, one from the Coast and Geodetic Survey, and one shall be appointed from civil life.

The sundry civil act of July 1, 1898, which appropriated funds for continuing this work, provided that the Board should "submit in their report the probable and relative cost of various depths for said waterway, respectively, as follows: 21 and 30 feet, with a statement of the relative advantages thereof."

The following appropriations for the work of the Board have been made by Congress:

| | |
|---|---|
| Sundry civil act of— | |
| June 4, 1897 | $150,000 |
| July 1, 1898 | 225,000 |
| March 3, 1899 | 90,000 |
| Urgent deficiency act of February 9, 1900 | 20,000 |
| Total | 485,000 |

## ORGANIZATION OF THE BOARD.

The Board held its first meeting at the Engineer Office, United States Army, at Philadelphia, Pa., on August 11, 1897, and organized by the election of Maj. (now Lieut. Col.) C. W. Raymond, Corps of Engineers, United States Army, as President. Gen. James H. Kidd, of Ionia, Mich., was appointed secretary of the Board by letter of the Secretary of War dated August 10, 1897. The permanent office of the Board was established at Detroit, Mich., on October 1, 1897.

Instructions for the guidance of the Board were issued by the Secretary of War on August 31, 1897, and amended instructions on October 20, 1897. These instructions will be found in Appendix No. 9.

## DUTIES OF THE BOARD.

The act of June 4, 1897, requires the Board to make surveys and examinations (including estimate of cost) of deep waterways, and the routes thereof, between the Great Lakes and the Atlantic tide waters, as recommended by the report of the Deep Waterways Commission transmitted by the President to Congress January 18, 1897. This report is published as Document No. 192, House of Representatives, Fifty-fourth Congress, second session. The recommendations referred to will be found on page 30 of the report, and are as follows:

### RECOMMENDATIONS.

I. That complete surveys and examinations be made and all needful data to mature projects be procured for—

(*a*) Controlling the level of Lake Erie and projecting the Niagara ship canal.

(*b*) Developing the Oswego-Oneida-Mohawk route.

(*c*) Developing the St. Lawrence-Champlain route.

(*d*) Improving the tidal Hudson River.

(*e*) Improving intermediate channels of the lakes.

II. That the collecting and reducing of existing information, supplemented by reconnoissances and special investigations, be continued until the general questions have been fully covered.

III. That a systematic measurement of the outflow of the several lakes and a final determination of their levels shall be undertaken.

The depths of the waterways which are the subjects of investigation are definitely fixed by the provisions of the act of July 1, 1898,

at 21 and 30 feet, respectively, and the act further requires a statement of the relative advantages thereof.

It will be observed that, with the exception of the provision last named, the duties of the Board are of a purely engineering character, and do not include the consideration of questions of Government policy or commercial desirability. In comparing the relative advantages of waterways of different depths, however, a consideration of the relative adaptability of these waterways to the present and prospective requirements of commerce has been found unavoidable.

## PLAN OF THIS REPORT.

The problems investigated by the Board require for their intelligent consideration a knowledge of the original conditions formerly existing in the lake and river waterways and of the improvements made therein. The report, therefore, commences with a brief statement of these conditions and a general account of these improvements. This is followed by a condensed statement of the operations of the Board and of the results obtained, full and detailed information with reference to methods and data being given in the appendixes. This plan is adopted for the sake of clearness.

Under the head of "Operations of the Board" an account is given of the general methods followed by the Board in conducting and supervising the work. Under the head of "Special investigations" an account is given of certain investigations made by members of the Board or by others under their immediate direction, the details of which are contained in the appendixes.

The subjects specified in Paragraph I of the recommendations of the commission of 1897 are then treated separately in order.

The systematic measurement of outflow and determination of lake levels provided for by Paragraph III of the recommendations have been carried out only so far as was necessary in investigating the other problems under consideration, and will be referred to in connection therewith. The commission of 1897 remarks in its report that this work will require some years of time, and that it is possible that it can be as well done through some other agency. It is now in progress, under the direction of the Corps of Engineers, United States Army. Finally, a comparison is made between the various waterways which have been surveyed and investigated, and a statement of the relative advantages of the waterways having depths of 21 and 30 feet, respectively, is given, as required by the act of July 1, 1898.

## ORIGINAL CONDITIONS AND IMPROVEMENTS.

From the time of the arrival of the first French explorers on the Great Lakes, in the seventeenth century, until the present the utilization of the great natural waterways through these lakes as a means for the development of new commerce has been a prominent factor in

the commercial and industrial progress of the country. It is only two hundred and twenty years since the first sail vessel was launched on the upper lakes, during which time the birch-bark canoe has been transformed into the steel freight steamship of 8,000 tons capacity, and a freight traffic of 40,000,000 tons annually has been developed from the natural resources of the country tributary to the lake system of waterways.

Without the facilities for easy transportation afforded by these waterways the lake cities would never have reached their present importance, and without the commercial and manufacturing requirements of these cities the unprecedented growth of the lake commerce would not have occurred. The Hudson River and the St. Lawrence River are the natural gateways of commerce on the Atlantic coast, and to connect these with the Great Lakes by a waterway of suitable dimensions to economically transport the commerce of the country tributary to the lake system has been the most important project for public improvements claiming the attention of the Governments of the United States and Canada during the past century.

Two general systems of canals have been constructed to secure through water navigation from the lakes to the Atlantic—one, by the Canadian government, around the rapids and obstructions of the Niagara and St. Lawrence rivers, and the other, by the State of New York, from Lake Erie to the Hudson River at Albany, both of which were inadequate for the demands of commerce when completed. The Canadian system has been enlarged three times, and the Erie Canal once, and the second enlargement commenced, and still, like a narrow-gauge railroad, their dimensions are not such as to form a satisfactory link between the larger transportation routes connected.

The possibilities for the growth of commerce were never sufficiently realized to warrant the construction of transportation routes on such broad principles as to anticipate the actual requirements by the time that the work could be completed, and no attempt was made to determine the channel dimensions which would ultimately be required to form a through transportation route from the lakes to the sea without the necessity of transferring freight at intermediate ports between which the waterways were not such as to meet the requirements of the economic freight carrier of the connected routes—a result which can only be obtained by making all such connecting waterways of dimensions to conform with the controlling depths of the routes connected.

On the lake waterways the improvement of depth has been a gradual one to correspond with depth of terminal harbors, and unlike the construction of canals, the money expended on such work has not been entirely lost when considered in reference to future enlargements. When the Erie Canal was first opened, Thomas Jefferson said that the project was one hundred years ahead of its time, yet within ten years afterwards it became necessary to commence enlarge-

ments which cost fully as much as though no work had been done. In order to clearly understand the situation relative to the development of a waterway to meet the future requirements as well as the present necessities of the commerce between the Great Lakes and the Atlantic, a brief review of the original conditions of the natural waterways, the improvements which have been made, and the artificial channels constructed will be necessary.

## HUDSON RIVER.

The watershed of the Hudson River above the Mohawk has an area of about 4,600 square miles, and the Mohawk watershed an area of about 3,400 square miles, making the total watershed tributary to the river at Troy 8,000 square miles, from which, at times of freshets, there is a maximum discharge from the Upper Hudson of about 65,000 cubic feet per second, and from the Mohawk River about 78,000 cubic feet per second. The times of the high waters of the two rivers are not likely to be coincident.

At times of low water, the entire volume of flow of both rivers (about 2,000 cubic feet per second) is utilized in the wheels of the manufacturing establishments at places where dams have been located for developing power.

In its original condition the Hudson River was a tidal stream from New York to Troy, above which the river consisted of a series of pools separated by rapids at points where the outcrop of rock in the river bed formed natural weirs.

The river had a natural navigable channel of 20 feet depth as far up as Hudson City, above which it gradually shoaled to about 10 feet at Albany and 6 feet at Troy, with shifting bars of only 4 feet to 5 feet on the crests. The mean tidal fluctuation at Troy was 0.8 foot, and the total low-water slope from Troy to New York 4.5 feet. The improvement of the channel has considerably increased the tidal range at Albany and Troy, and diminished the low-water slope of the river, and if a 21-foot channel should be constructed, the resulting increase of tidal effect would materially assist in maintaining the improved channels.

The conditions arising from ice jams, the wash of channel banks, and the formation of shoals indicate that navigable depths of over 21 feet will be difficult and expensive to maintain.

The principal obstructions to the navigation of the Hudson were between Troy and New Baltimore, a distance of about 20 miles, which, before improvement, consisted of 14 bars with only 4 to 5 feet of water on the crests.

The improvement of this reach of river was commenced by the State of New York in 1797, and during the following twenty-two years, $185,700 were expended in the construction of dams and jet-

ties, which resulted in washing away valuable land and creating new shoals without improving navigation.

In 1834 the United States Government assumed charge of the river improvement, since which time, with the amount contributed by the State of New York, about $5,000,000 have been expended on the project, which provides for a channel 12 feet deep and 300 feet wide from the State Dam to Broadway, in Troy, and 400 feet wide from Broadway to Coxsackie.

## NEW YORK STATE CANAL PROJECTS.

The first mention of interior waterway improvements in New York is found in the recommendation of Sir Henry Moore, governor of the colony, to the assembly, on December 16, 1768, for the improvement of the Mohawk River at the Falls of Canajoharie.

In 1784 a survey was made for a canal around Niagara Falls, to be utilized in connection with a system of canals and slack water, by the way of the Oswego and Mohawk rivers, to connect the Hudson River with Lake Erie, which was further considered in 1788 by Elkanah Watson, who proposed a project for improvement of transportation between Lake Ontario and the Hudson by connecting Wood Creek with the Mohawk River by a canal and by improving these streams and the Oswego River.

The first canal law was passed March 24, 1791, authorizing an exploration for a canal from Fort Stanwix to Wood Creek and surveys for the improvement of the Mohawk River to the Hudson, for which $500 were appropriated. The commission appointed to superintend this work was composed of Elkanah Watson, General Schuyler, and Goldsborrow Banger, who reported that the project was feasible, and that the existing cost of transportation from Seneca Lake to Albany was from $75 to $100 per ton and required about four weeks for the round trip. On March 30, 1792, a law was passed incorporating two companies—the Western, to provide transportation from the Hudson to Lake Ontario, and the Northern, from the Hudson to Lake Champlain. The State afterwards subscribed to the stock of the companies.

In the spring of 1796 the western canals were opened from Schenectady to Seneca Falls for boats of 16 tons capacity, and freight charges were reduced to $32 per ton for the down trip and $16 per ton for the upbound trip.

The amount expended by the Western Company up to 1813 was $400,000. The total length of artificial channel of the system was about 15 miles, and the locks, which were first built of wood and afterwards changed to brick, never worked well. The rights of the company were finally purchased by the State in 1820. The Northern Company expended about $100,000 on the route from the Hudson to Lake Champlain, which was a total loss. In 1798 a law was passed for a canal around Niagara Falls, but no action was ever taken to put it into effect.

## ERIE CANAL.

The first suggestion of the Erie Canal is attributed to Gouverneur Morris, in 1803, and was then generally regarded as "an effusion of an eccentric mind." In 1808 the legislature appropriated $600 for a survey of the route, with the expectation that the Federal Government would aid in the construction. This act contemplated a waterway from the Hudson to Lake Ontario and a canal thence around Niagara Falls to Lake Erie.

In 1811 a commission, consisting of Gouverneur Morris, S. Van Rensselaer, De Witt Clinton, William North, Thomas Eddy, and Robert R. Livingston, was appointed to consider and report on all matters relating to the inland navigation of the State. This commission made an appeal to Congress and to the State government for aid, but without success, and in April, 1812, submitted a report, the recommendations of which were made the basis of legislation for the construction of the canal on the line as finally built.

In their report it is stated that the project for a canal suitable for vessels of 50 to 60 tons capacity, capable of navigating Lake Ontario, was impracticable for the reason that sufficient water was not available for the supply of the summit level, and inadvisable for the reason that freight for export, once having reached Lake Ontario, could be delivered at Montreal for less cost for transportation than at New York, an argument which is still an important factor in the location of a waterway from the lakes to the sea. At that time a large amount of the commerce of New York City was from the central and western part of the State, making a canal through the State much more advantageous than a route through Lake Ontario, passing around the western half of the section to be benefited, a condition which has been greatly modified by the enormous increase of through traffic and the development of railroad transportation lines by which local commerce is economically handled.

In 1812 the legislature passed a law appropriating $5,000,000 for the construction of the canal, but owing to the war with Great Britain the act was repealed before any work was done.

On April 16, 1816, a law was passed for an estimate for the canal, and the following year the construction was authorized. The first ground was broken July 4, 1817, at Rome, and in October, 1819, the first boat made the trip from Rome to Utica. During 1821 the entire canal was placed under contract and was completed in October, 1825.

It was recognized before the canal was completed that its dimensions were inadequate for economical transportation, and in 1834 a law was passed authorizing the enlargement of the system and providing for a second set of locks of the enlarged plan from Syracuse to Albany. In May, 1835, a law was passed approving the policy of enlargement of the entire canal, which was not completed until 1862.

## CHAMPLAIN CANAL.

The law of 1817 providing for the construction of the Erie Canal also provided for the Champlain Canal, which was completed in sections, as follows:

1819. From Fort Edward to Whitehall.
1820. From Whitehall to Fort Miller.
1821. From Fort Miller to Stillwater.
1822. From Stillwater to Waterford.
1823. From Waterford to Albany.

This canal was gradually enlarged and the locks replaced until 1860, when the legislature directed that the depth be made 5 feet and the bottom width 35 feet.

## OSWEGO CANAL.

This canal was authorized in 1825 and completed in 1828, with the same dimensions as the original Erie Canal. The report of the State engineer for 1854 states that the business of this canal was greatly increased, at the expense of the western portion of the Erie Canal, by the completion of the Welland Canal, indicating that the opinion that freight having reached Lake Ontario would not be locked over the divide to the Mohawk River was not well founded.

The following table gives the dates of construction, dimension of prism, size of locks, and cost of these canals as originally built, and for the enlargements completed in 1862:[1]

| Name of canal. | When authorized. | When completed. | Length. | Width on surface. | Width on bottom. | Depth of water. | Number of locks. | Length of locks. | Width of locks. | Original cost of the canal. | Cost, including enlargement and land damages. | Total cost, including interest on loans. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Miles.* | *Ft.* | *Ft.* | *Ft.* | *Ft.* | *Ft.* | *Ft.* | | | |
| Erie Canal | 1817 | 1825 | 363 | 40 | 28 | 4 | 83 | 90 | 15 | $7,143,790 | | |
| Enlargement | 1835 | 1862 | 350½ | 70 | 56 | 7 | 71 | 110 | 18 | | $38,977,831 | $52,491,916 |
| Oswego Canal | 1825 | 1828 | 38 | 40 | 24 | 4 | 18 | 90 | 15 | 565,437 | | |
| Enlargement | 1847 | 1862 | 38 | 70 | 56 | 7 | 18 | 110 | 18 | | 3,077,430 | 3,612,825 |
| Champlain Canal | 1817 | 1822 | 66 | 50 | 35 | 5 | 20 | 100 | 18 | 921,011 | 1,746,063 | 2,647,002 |

*Total cost of the Erie Canal in detail.*

| | |
|---|---|
| Original cost of 363 miles of canal | $7,143,790 |
| Enlargement of 350½ miles of canal | 31,834,041 |
| Total cost, exclusive of feeders, structures, and land damages | 18,439,849 |
| Cost of feeders | 794,618 |
| Cost of structures for old canal and enlargement | 16,494,218 |
| Cost of land damages for old canal and enlargement | 3,249,146 |
| Total interest on loans during construction and enlargement | 13,514,085 |
| Total cost, including interest on loans | 52,491,916 |
| Total cost of repairs, 1827 to 1862 | 10,995,333 |

[1] Compiled from the report of State engineer and surveyor of New York for 1862.

In 1895 $9,000,000 were appropriated by the State of New York to make the locks twice their present length and deepen the canal to 9 feet. After the expenditure of most of the money the amount appropriated was found to be inadequate and the work discontinued.

PROPOSED SHIP CANALS.

In 1835 Capt. W. G. Williams, United States topographical engineers, made surveys for five different routes from Schlossers, on Niagara River, above the Falls, to points on the river near Lewiston, and from Tonawanda to Olcott, on Lake Ontario.

The estimates were on a basis of a canal prism 10 feet deep, 110 feet wide at the surface, and with locks 200 feet long, 50 feet wide, and 10 feet deep, and varied from $2,568,900 for the Lewiston line to $5,041,725 for the Tonawanda–Olcott line.

In 1853 surveys were made under the direction of a State commission from Tonawanda to points on Lake Ontario for a canal 130 feet wide on bottom, 14 feet deep, with locks 300 feet long and 70 feet wide. The estimates varied from $10,290,500 for canal with single locks to $13,169,600 for canal with double locks.

In 1863 these lines were again surveyed by Mr. Charles B. Stuart for the General Government and an estimate for a canal 105 feet wide at the surface and 12 feet deep, with locks 275 feet long by 45 feet wide, reported at $6,007,000 for a canal with single locks and $7,680,600 for canal with double locks.

In 1867 Lieut. Col. C. E. Blunt, Corps of Engineers, United States Army, made surveys of 3 routes from Schlossers, on the Niagara River, about 3 miles above the Falls, to the river near Lewiston; 1 from Schlossers to Lake Ontario at mouth of Four-mile Creek, 1 to Wilson, on Lake Ontario, and 1 from Tonawanda to Olcott, at the mouth of Eighteen-mile Creek. The estimates were based on a canal 90 feet wide at the bottom, 125 feet wide at the surface, and 14 feet deep, with locks 275 feet long and 36 feet wide, with lifts of 15 feet and 16 feet, and varied from $11,032,000 for the Lewiston line to $12,893,000 for the Olcott line.

In 1884 Mr. E. Sweet, engineer and surveyor of New York State, read a paper before the American Society of Civil Engineers, outlining a project for a down-grade canal 18 feet deep from Tonawanda to Utica, and thence by locks and dams on the Mohawk to Troy. The project called for a high aqueduct 2 miles long, at the crossing of the Seneca River, where the natural conditions are not suitable for safe foundations for such a structure. It is, however, probable that, by adopting a low-level canal from Oneida Lake to the Mohawk, and diverting the Seneca River east of Baldwinsville so as to carry that level to Oneida Lake and passing over the outlet of Onondaga Lake, such a down-grade canal could be safely constructed, the only question being whether such route would not be much more expensive and

would take 30 per cent more time to navigate than the route via Lake Ontario.

In compliance with the river and harbor act of August 11, 1888, a revision was made of the surveys of the Wilson and Olcott routes by Capt. C. H. Palfrey, Corps of Engineers, United States Army, and an estimate for a canal 100 feet wide at the bottom, 20½ feet deep, with locks 400 feet long, 80 feet wide, and 18 feet lift, was reported, as follows:

| | |
|---|---|
| Wilson route, 18.25 miles: | |
| With single locks | $24,201,600 |
| With double locks | 29,347,900 |
| Olcott route, 25.28 miles, single locks | 23,617,900 |

Under the provisions of the sundry civil appropriation act of March 2, 1895, the President appointed James B. Angell, John E. Russell, and Lyman E. Cooley members of a commission to meet and confer with a similar commission from Canada, and report whether it is feasible to build such canals as shall enable vessels to pass to and fro from the Great Lakes to the Atlantic Ocean.

After a year's investigation and study of available data the commission reported, "That it is entirely feasible to construct such canals and develop such channels as will be adequate to any scale of navigation that may be desired between the Great Lakes and the seaboard," and recommended that complete surveys be made on which to base projects for ship canals from Lake Erie to Lake Ontario and from Lake Ontario to the Hudson River via the Oswego and Mohawk rivers and via the St. Lawrence River and Lake Champlain.

In compliance with the river and harbor act of June 3, 1896, Maj. T. W. Symons, Corps of Engineers, United States Army, made an estimate from existing data for "cost of construction of a ship canal by the most practicable route, wholly within the United States, from the Great Lakes to the navigable waters of the Hudson River, of sufficient capacity to transport the tonnage of the lakes to the sea." Major Symons interpreted tonnage to mean the commerce of the lakes, without regard to the size of vessels in which transported on the lakes, and recommended a barge canal 12 feet deep, 82 feet wide at the bottom, and estimated to cost $50,000,000.

The history of the Erie Canal shows the amount of freight carried to be as follows:

| | Tons. | | Tons. |
|---|---|---|---|
| 1837 | 667,151 | 1880 | 4,608,651 |
| 1850 | 1,635,089 | 1890 | 3,303,929 |
| 1860 | 2,253,533 | 1899 | 2,419,084 |
| 1870 | 3,083,132 | | |

Since 1880, when the traffic of the Erie Canal reached a maximum, the rate per ton mile on the railroads from the lakes to the seaboard has been about double that on the Erie Canal, yet during that time the business of the canal has diminished about one-half, showing

beyond question that the volume of freight which will be shipped by any given route does not depend entirely upon the relative cost of transportation, and that, unless the conditions which have produced the decline of traffic on the canal are changed, any increase in the carrying capacity will produce no material increase in the volume of freight carried.

### CANADIAN CANALS.

Since 1821 the Government of Canada has expended upward of $80,000,000 on the construction and improvement of canals, with results somewhat similar to those developed by the waterways through New York.

The first Canadian canals constructed were those to overcome the Cedar and Coteau rapids, which were commenced in 1779 and completed in 1781. The locks were of cut stone, with a chamber 6 feet wide, 2½ feet deep, and designed for boats carrying 30 barrels of flour. These locks were enlarged in 1804 and 1817, and abandoned in 1845.

A canal with locks to overcome the rapids at Sault Ste. Marie was constructed by the Northwest Company in 1797 for passing loaded canoes. One of these locks is still in a fair state of preservation.

In the St. Lawrence River canal system—

The Lachine Canal was begun in 1821 and opened in 1825.

The Beauharnois Canal was begun in 1842 and opened in 1845.

The Cornwall Canal was begun in 1834 and opened in 1843.

The Farrans Point Canal was begun in 1844 and opened in 1847.

The Rapid Plat Canal was begun in 1844 and opened in 1847.

The Galops Canal was begun in 1844 and opened in 1846.

The Welland Canal was begun in 1824 and opened in 1829.

The Welland Canal was enlarged between 1841 and 1850, and in 1873 was made 12 feet deep, and in 1887 was deepened to 14 feet. In 1871 it was decided to enlarge the canals of the St. Lawrence River system to afford a depth of 12 feet throughout, which project has since been modified and all the locks on the route made 45 feet wide and 14 feet deep on the sills. The locks (where not made for fleets of barges) are 270 feet long, and are intended to pass lake steamers of 2,000 tons capacity. The completion of this system of waterways from Lake Erie to tide water, capable of passing vessels of twice the capacity of the proposed New York State Barge Canal, does not indicate that the causes which have produced the decline in water transportation between the lakes and the Atlantic have been overcome.

### LAKE HARBORS AND WATERWAYS.

The entrance to Niagara River from Lake Erie was originally a winding channel about 17 feet deep at mean lake level through Horse Shoe Reef, which, in accordance with a project approved in 1888, was deepened to 18 feet for a width of 400 feet. This cut through the natural

barrier to the discharge of the lake undoubtedly had the effect to slightly lower the natural levels.

Previous to 1819, the mouth of Buffalo Creek, which constitutes the interior harbor at Buffalo, was closed most of the time by a gravel bar. In 1820 and 1821, two piers about 200 feet apart were built across the bar by the State of New York, which were transferred to the United States in 1826.

From 1830 to 1867 various projects were submitted for the improvement of the harbor entrance and construction of breakwaters, but none of them were carried out until 1868, when it was decided to repair and extend the piers, dredge to a depth of 15 feet between them, and construct a breakwater 4,000 feet long in 27 feet of water outside of the harbor entrance. The project has since been gradually enlarged until the present, and consists in extending the detached breakwater to Stony Point, about 4 miles from the entrance of the harbor, and to deepen the harbor for 20-foot navigation.

The 21-foot curve in the lake is about 1,200 feet outside of the outer end of the piers, and the 30-foot curve about 14,000 feet outside of the entrance.

The entrance to the harbor and deep waterway channels, if less than 23 feet in depth, will be protected by the breakwater as now constructed; but for greater depths the channel excavation will be in the open lake, across which at times there will be very heavy currents, which will probably produce rapid deterioration of the channel from the material carried by the currents and ice.

The harbors on the south shore of Lake Erie had original depths of from 3 feet to 6 feet, which have been generally improved by building piers about 200 feet apart and dredging between to depths of 16 feet to 19 feet. The 30-foot curve in lake is from 3,000 to 4,000 feet from shore in front of the harbor entrances.

At the mouth of the Detroit River, with the exception of a few sand bars, there is a natural 21-foot channel into the lake at mean stage, but for a 30-foot channel the bed of the lake would have to be deepened for a distance of about 10 miles, from which points the route through the islands, about 35 miles, varies in depth between 30 feet and 40 feet.

The Detroit River, with the exception of a reach of about 5 miles near its mouth, has a natural 30-foot channel. At the Limekiln crossing, about 1 mile above Amherstburg, the original depth was only 13 feet, above and below which for a total distance of about 4 miles there were reefs of bowlders and rock, with depths of 15 to 18 feet. Through this reach of the river a channel has been excavated having a width of 440 and a depth of 18 to 20 feet.

The river currents are at places across the channel, making it dangerous to navigate in its present condition.

Previous to the improvement of the channel across Lake St. Clair a

large shoal off Grosse Point obstructed navigation for vessels drawing over 16 feet at mean stage, through which a channel 20 feet deep has been dredged.

Lake St. Clair has at present a depth of 20 feet at mean stage from the head of the Detroit River to the delta of the St. Clair River, a distance of about 15 miles, and in order to establish 30-foot navigation between Lakes Huron and Erie a channel 10 feet deep would have to be excavated in the bed of the lake for this distance. From the South Channel of the St. Clair River into the lake there was originally a narrow winding channel from 9 to 18 feet deep. In 1871 a straight channel 13 feet deep between piers 300 feet apart was completed from the deep water in the river to the 13-foot curve in the lake. This channel was deepened to 16 feet in 1873, and to 20 feet in 1894, for which depth the dredged channel extends 1 mile outside of the piers into the open lake.

The St. Clair River has a natural depth of over 30 feet, except across the middle grounds at Port Huron, Marysville, and St. Clair, where the depths are from 21 feet to 24 feet. The maintenance of a 30-foot channel through these reaches will require a rectification of the channel banks or dredging at frequent intervals.

The general depth of the foot of Lake Huron, 1½ miles above the head of the St. Clair River, was originally about 21 feet to 27 feet, over which were scattered numerous shoals with only 16 to 18 feet of water.

A channel 2,400 feet wide and 21 feet deep at mean stage has been cut through these shoals. At the time of the last complete survey of the head of the river, in 1867, the depth across the bar over which the lake discharges into the St. Clair River was only 27 feet, and through the gorge at the head of the river the central depth was 48 feet.

Investigations made during 1898 and 1899 show that a channel has been scoured through the bar 75 feet deep, and the depth in the gorge at the narrowest place increased from 48 feet to 66 feet.

There is now a channel over 40 feet deep from the lake into the river, the increased outflow through which has lowered the general level of Lake Huron and Michigan about 1 foot.

From the foot of Lake Huron to Milwaukee and Chicago there are no natural obstructions to 30-foot navigation outside of harbor entrances, although the marking or removal of some shoals at the foot of Lake Michigan may be found desirable.

Chicago River is a small stream, which, before improvement, was closed most of the time by a bar across its mouth. Its entrance has been improved by piers and dredging, and the river widened to a width of from 200 feet to 300 feet, and dredged about 18 feet deep.

For 30-foot navigation on the lakes the business of the port would have to be transacted from slips constructed in the outer harbor, where the depth of water is now only about 14 feet, or by deepening the river to 30 feet.

The St. Marys River is the only waterway from Lake Superior to the lower lakes, and before improvement was obstructed in many places by bowlders and rapids, the principal fall being at Sault Ste. Marie.

The fall of the river from Lake Superior to the head rapids was about 0.5 foot, in the half mile of rapids 18 feet, and from foot of rapids to Lake Huron about 2.3 feet. Since the improvement of the river and the enlargement of the head of the St. Clair River, the general level of Lake Huron and of the St. Marys River has been lowered so that the fall in the rapids is now about 19 feet.

The governor of the State of Michigan, in 1837, recognizing the immense importance of the timber and mineral resources of the Lake Superior region, called the attention of the State legislature to the advisability of constructing a canal around the rapids at Sault Ste. Marie, and three years later the importance of the project was discussed in the United States Senate. Nothing, however, was done until 1852, when a grant of 750,000 acres of public land was made to the State of Michigan, from the proceeds of which the canal was to be built. Work was commenced in 1853 and the completed canal turned over to the State in 1855. The canal was 5,400 feet long, 100 feet wide at water surface, and 12 feet deep, with locks 350 feet long, 70 feet wide, 11½ feet deep on the miter sills, and 9 feet lift.

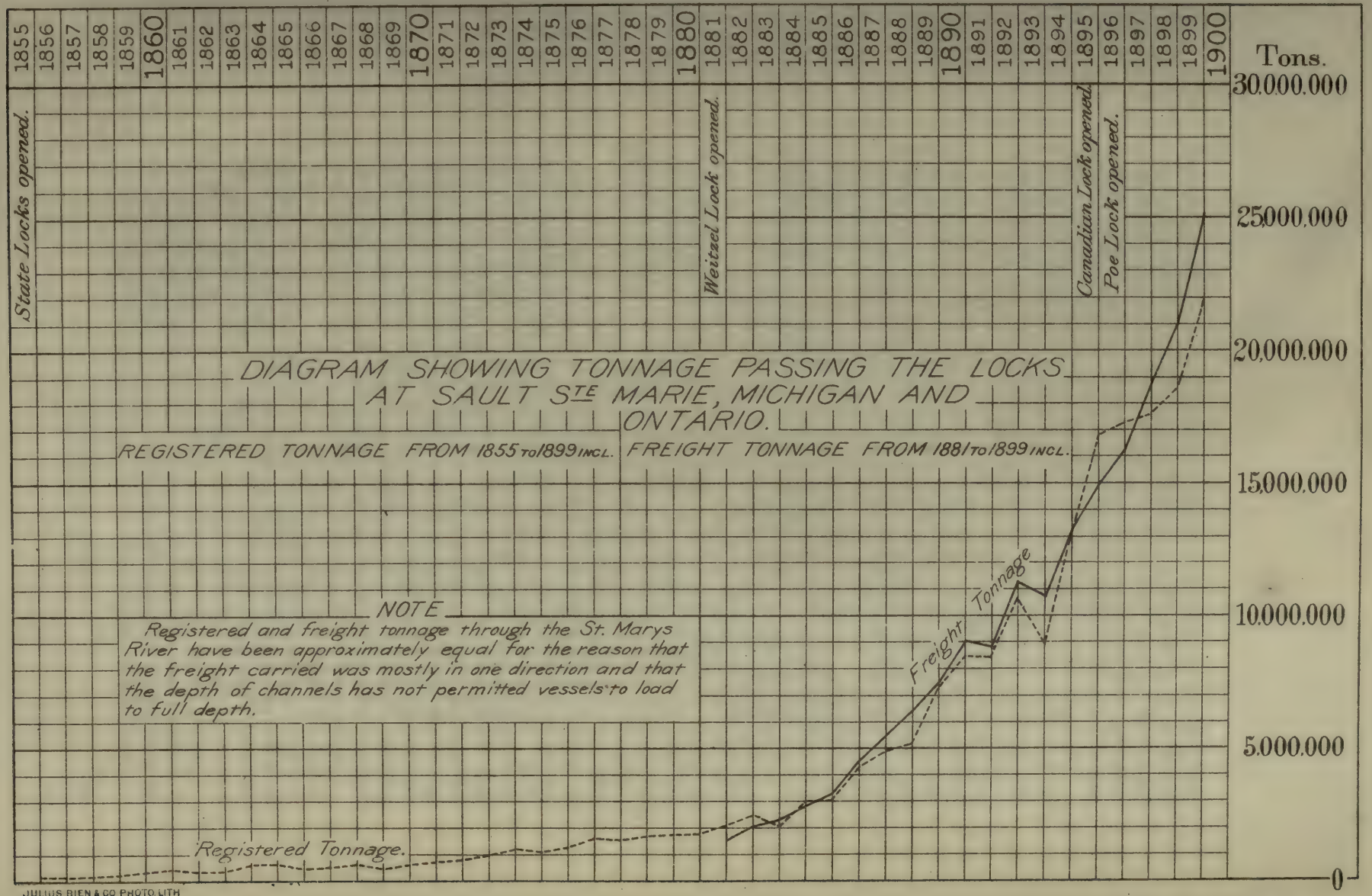
The branch of the St. Marys River flowing to the north and east of Sugar Island was considered best adapted for the improvement required by the depth of water in the locks, and a project was approved in 1856 for removing the obstructions to navigation by dredging to a depth of 14 feet through Lake George and the East Neebish Rapids, which work was not completed until 1871.

It was recognized soon after the completion of the State locks that the dimensions of waterway and facilities afforded were inadequate to accommodate the growing commerce of Lake Superior, and in 1870 the General Government commenced the improvement of the canal, comprising the deepening to 16 feet and the construction of a new lock 515 feet long, 80 feet wide, 16 feet deep on miter sills, and 18 feet lift, which was completed in 1881. The lowering of the level of Lake Huron, which has occurred since the completion of the work, has increased the lift to about 19 feet and diminished the depth on the lower miter sill to about 15 feet.

In connection with the lock construction at the rapids, the obstructions in the river channel between Lake Superior and Lake Huron were dredged to a depth of 16 feet, which work was completed in 1883.

The commerce of Lake Superior reached such proportions in 1884 that a project for a larger lock with 21 feet of water on miter sills was proposed, and in 1886 the project was modified and work commenced. This lock, 800 feet long, 100 feet wide, and 21 feet deep, was completed in 1896, and in the meantime a channel 300 feet wide and 20 feet deep was dredged through the Hay Lake and the Middle Neebish

FIG. 1

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Rapids branch of the St. Marys River to the east of Sugar Island. A lock 900 feet long, 60 feet wide, and 21 feet deep was completed in 1895 on the north side of the St. Marys Rapids by the Canadian government.

The channel of the St. Marys River below the rapids is not of sufficient capacity to allow the safe passage of the volume of commerce already developed between Lake Superior and the lower lake ports, and an enlargement to a width of 600 feet will be a necessity in the near future. This enlargement can best be effected by widening the present Hay Lake channel to the Neebish Rapids, and thence by a new channel through the West Neebish to Mud Lake, which is understood to be the project for improvement now contemplated.

The distance through this channel from 30 feet of water in Lake Superior to Lake Huron is 58 miles, of which 32 miles will have to be deepened to establish a 30-foot navigable channel between Lakes Superior and Huron.

From the head of the St. Marys River to Duluth there are no obstructions to 30-foot navigation.

The project for the improvement of Duluth Harbor, now under construction, provides for a 20-foot depth at low stage of lake, between piers 300 feet apart. To increase the depth of this harbor, so as to provide for 30-foot navigation, would cost about $5,000,000.

The cost in the past to the Government for improving the entrances of lake harbors and connecting waterways 1 foot has been about $5,000,000, and since this cost increases rapidly with the additional depth and width of channel secured an increase of 10 feet in depth for the entire system of harbors and connecting waterways would probably amount to over $70,000,000.

The controlling influences which fix the economical dimensions of an intermediate transportation route which will satisfy both present and future requirements are the volume of existing traffic, the volume which may be expected to develop with improvement of transportation facilities, and the limiting depths of the water routes to be connected.

From a careful examination of the original conditions, the improvements which have been made, and the difficulties to be overcome to increase existing depths through the lake waterways and in the Hudson River, it seems very evident that a depth of 30 feet through these channels will be very difficult and expensive to develop and maintain.

The economical features of the problem pertaining to the proper dimensions of the connecting waterways will be discussed under the chapter on the relative advantages of routes of different depths.

The necessity of making a connecting waterway conform in dimensions with those of the routes connected is well illustrated by the commerce developed by the various improvements which have been made for increasing transportation facilities between Lakes Superior and Huron, shown on the accompanying figure.

## OPERATIONS OF THE BOARD.

At its first meeting, held in Philadelphia August 11, 1897, the Board adopted rules and regulations for the guidance of its employees and outlined the scope of the investigations to be made. It was deemed essential, in order to complete the investigations required under the act in a satisfactory and economical manner, that the Board be relieved from conducting the work in compliance with the rules of the Civil Service Commission, and on a recommendation to that effect the following instructions were issued by the Secretary of War:

> The said commission is authorized to rent such necessary office rooms (except in the city of Washington), and, when the exigencies of the service will not admit of advertisement and contract, to purchase in open market such materials, including instruments, books, maps, field outfits, provisions, and other supplies of any kind as in its judgment are deemed necessary for the prosecution of its work, and to employ such assistance as it may deem essential and to pay such compensation therefor as it may deem proper.

Under these instructions the general policy was adopted to have all work executed under the supervision of at least one member of the Board, and that the assistant engineers having responsible charge of divisions of the work should select the personnel of their respective parties, subject to the approval of the Board. General instructions were prepared and issued for the guidance of field and office engineers,[1] a careful reconnoissance of all lines was made by the Board in advance of field work, and special instructions were given on the ground covering the amount and character of surveys and investigations to be made.

The office of the Board at Detroit has been under the immediate personal supervision of Mr. George Y. Wisner, member of the Board, and he has given close and continuous attention to the work of the Board throughout the whole period of its operations. The other members have at times been compelled to give attention to other important matters, the services of Lieutenant-Colonel Raymond having been required elsewhere for military purposes during the war with Spain, and Mr. Noble having been absent from the country in connection with his duties as a member of the Isthmian Canal Commission. The active working membership of the Board has therefore averaged only two members during most of the period covered by the work. All the work done under the Board has, however, been carefully examined by every member, and all points of importance have been decided by all.

Special investigations have been made by the individual members of the board relative to the form and dimensions of canal prism to be adopted, the kind and size of lock structures best adapted for the proposed work, the design of breakwaters for the lake terminals, the method and cost of regulating the level of Lake Erie and Lake Cham-

[1] See Appendix No. 9.

plain so as to maintain as nearly a constant stage as possible, the relative advantages of routes of different depths, the speed of vessels in restricted waterways, and the unit prices to be used in making estimates, the results of which have been discussed by the full Board as the work progressed, and modified so as to embody the views of all the members.

The survey of the Niagara ship canal was commenced in September, 1897, and, including borings, was completed in April, 1898. The work consisted in developing two routes from Lake Erie to Lake Ontario, one from Buffalo, via the Niagara River, to Tonawanda, and thence by ship canal to Olcott, on Lake Ontario, and the other by the Niagara River to Lasalle, near the lower end of Grand Island, and thence by ship canal to the Niagara River at Lewiston, from which place there is a good natural channel to Lake Ontario. The topography of the country was determined with sufficient accuracy to develop contours of 2-foot intervals on the field maps, and borings were put down at such points as necessary to establish the profile of the rock surface where above canal grade, along the line of the proposed waterway as finally located on the field maps. Fourteen diamond-drill borings were afterwards put down along the location for these two lines to ascertain the character of material to be excavated and the nature of foundations on which structures are to be founded.

The Oswego-Mohawk route was divided into two divisions and the surveys and investigations carried on by two parties working toward each other from the terminals, for the purpose of completing the field work in a single year, if possible. Work was commenced in October, 1897, at Oswego, and was completed to the connection with the work of the eastern division at Herkimer in January, 1899, with the exception of a substitute line afterwards run from Minetto to Lake Ontario near the western end of Oswego Harbor, which was surveyed in July, 1899, and adopted as a portion of the proposed route. Seven diamond-drill borings were put down on the line in 1899 to determine the nature of the rock to be excavated and the character of foundations of proposed structures.

The field work of the eastern division of the Oswego route was commenced at Troy in October, 1897, and completed to Herkimer in November, 1898, with the exception of the survey of the cut-off line from the Mohawk at Schenectady to the Hudson below Albany, which was finished in June, 1899. The surveys were continued on these lines throughout the winter of 1897 and 1898, but heavy snowstorms and extreme cold weather made the work slow and expensive. A special investigation to determine the availability of an adequate water supply for this route was commenced in August, 1898, and continued for a year, during which time reservoirs were located in the valleys of the Black and Salmon rivers and a feeder line surveyed and mapped from the reservoirs to the proposed waterway near Rome.

The surveys of the St. Lawrence-Champlain route were made by three different parties—one on the Hudson River division from Troy to deep water in Lake Champlain; one from Lake Champlain, at Kings Bay, to Lake St. Francis, on the St. Lawrence, and one on the St. Lawrence River division, from Ogdensburg to Lake St. Francis.

The field work of the Hudson River division was commenced at Troy in April, 1898, and completed to Port Henry, on Lake Champlain, in January, 1899. The survey of the route from Lake Champlain to Lake St. Francis was commenced in July, 1898, and completed in May, 1899 (including four diamond-drill borings), and the St. Lawrence River investigations were commenced in August, 1898, and finished in June, 1899.

A survey of the Hudson River from Troy to Hudson was commenced August, 1898, and continued until stopped by unfavorable weather conditions in November, and was resumed the following spring and completed in May, 1899.

Arrangements were made with the United States engineer officer in charge of the surveys of the north and northwest lakes in 1898 by which the two offices were to have the use of the notes of work done under the direction of either pertaining to the levels, slopes, and discharge of the St. Clair, Niagara, and St. Lawrence rivers, and thereby avoid the duplication of work.

Under this arrangement the slopes of the St. Clair, Detroit, and St. Lawrence rivers were determined by lines of precise levels run in the fall of 1898 and spring of 1899, and permanent bench marks set for future reference.

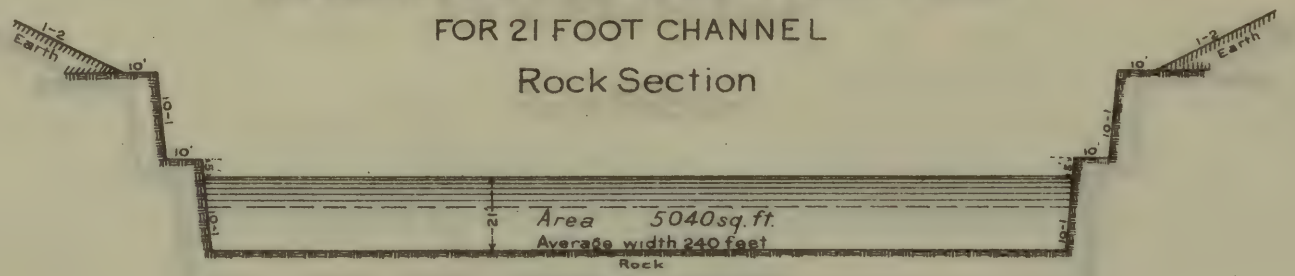
Two series of observations were made in 1897 and 1898 to determine the discharge of the Niagara River for different stages of Lake Erie, and a small number of observations were made for the discharge of the St. Lawrence River.

Under the direction of the Board a special survey was made of the foot of Lake Erie and the head of the Niagara River in 1898, on which to base designs of structures for regulating the level of Lake Erie.

From the investigation of this problem and the design of dams for controlling the flow of the Oswego, Mohawk, and Hudson rivers, it was found very desirable that the coefficients of the hydraulic formula for the flow of water over dams be determined for greater depths than those on which the coefficients were based, and through the courtesy of Prof. E. A. Fuertes, director of the College of Civil Engineering of Cornell University, the hydraulic laboratory of the college was placed at the disposal of the Board for making experiments on the volume of flow over weirs of different shapes. Prof. Gardner S. Williams, engineer in charge of the laboratory, gratuitously devoted a large amount of time to the installation of apparatus and weirs and to superintending the observations, the results of which have been of great value to the Board and will undoubtedly be highly appreciated by hydraulic engineers throughout the world.

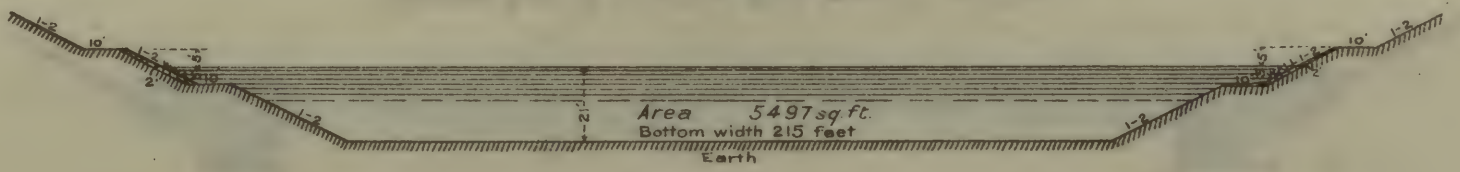
# STANDARD CROSS SECTIONS OF CANAL PRISM FOR 21 FOOT CHANNEL

## Rock Section



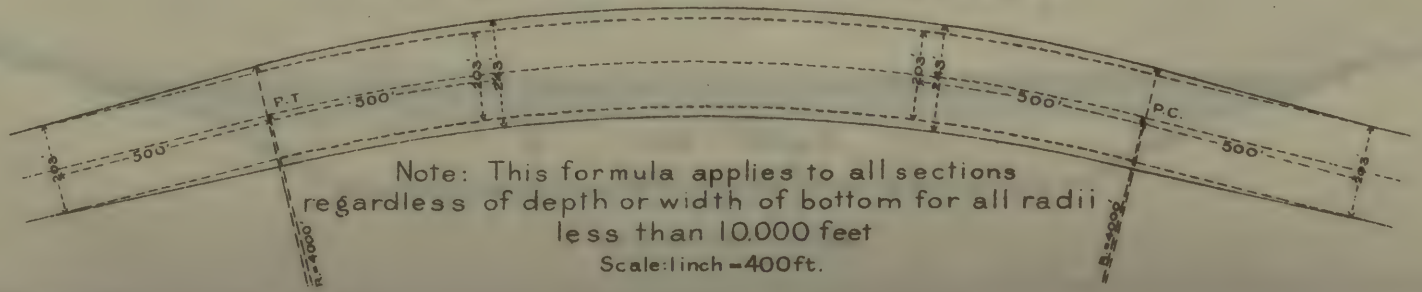

Scale 1 inch = 50 Feet

## Earth Section




## Formula for increasing the width of Canal on curves

Total increase of width = 60 -.005 Radius




Note: This formula applies to all sections regardless of depth or width of bottom for all radii less than 10.000 feet

Scale: 1 inch = 400 ft.

O.B.H

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The detail maps of surveys were completed as rapidly as possible as the work progressed by the office force of the field parties, and on the completion of the investigations of each division such members of the parties as were needed for making estimates were transferred to the main office at Detroit, where the proposed routes were located on maps by the Board, and designs of structures and estimates of cost prepared.

Careful studies have been made of the proposed location of all the routes investigated, with especial reference to securing the best alignment possible for the waterways at a minimum cost and to leave water-power privileges in as nearly their natural conditions as possible.

A corps of efficient engineers and draftsmen has been maintained throughout the investigations for the purpose of making thorough studies to determine the dimensions of structures and the design of lock gates best adapted for the large locks and high lifts necessary to secure economical construction and a minimum loss of time for the passage of vessels.

## OUTLINE OF INVESTIGATIONS.

The problems which the Board has investigated involve the application of the laws of flowing water over dams where the conditions are different from those for which hydraulic formulæ have been determined and the consideration of structures of greater magnitude than heretofore constructed.

The investigation of the physical characteristics of routes, the slopes and discharge of rivers, the development of a project for the control of lake levels, and the design of structures on which to base estimates were taken up as soon after the organization of the Board as the necessary engineering force could be secured, the results of which are fully discussed in the respective appendixes on these subjects.

### PRISM DIMENSIONS.

From a careful study of the dimensions of the St. Clair Flats Canal, the Suez Canal, the Manchester Canal, the Amsterdam Canal, the Kiel Canal, and the speed which steamships can maintain in these respective waterways, it is the opinion of the Board that the cross section of the canal prism should be made such that a speed of 8 miles per hour can be maintained on tangents without danger to passing ships or damage to the canal banks.

Referring to the discussion of the speed of ships in the proposed deep waterway, in Appendix No. 4, it will be noted that for the type of vessels best adapted for the economical transportation of the lake traffic the cross section of canal prism necessary to permit a speed of 8 miles per hour is about 5,500 square feet for a 21-foot waterway and 8,000 square feet for a 30-foot waterway.

The standard cross sections on which estimates are based and the formula for increasing the width of the prism on curves are shown in figures 2 and 3.

On open rivers, where the channel banks are not defined, a bottom width of 600 feet has been adopted as necessary for safe navigation, and on the Hudson and Mohawk, where the banks of the canalized rivers are liable to erosion at times of freshets, the cross section of waterway has been designed with reference to carrying the flood discharge with current velocities not exceeding 4 feet per second. On the lower Mohawk the economical cross section for carrying the flood discharge of the river with a current velocity of less than 4 feet per second requires a depth of over 21 feet, for which reason the dimensions and cost of the 21-foot and 30-foot waterways are approximately the same from Little Nose, 6 miles above Fultonville, to Rotterdam, where the waterway leaves the river channel.

To locate a waterway 21 feet deep down the Mohawk Valley independent of the river channel would involve a large amount of river rectification, and would cost more than to canalize the river for 21-foot navigation. The latter method of improvement will, however, give a channel which can be navigated in less time and with less danger of accident than the former.

Referring to the estimates of the Mohawk and the Champlain routes, it will be noted that the 30-foot waterway by the former and the 21-foot waterway by the latter route are the cheapest to construct. This apparent anomaly is due to the large amount of rock excavation required for the 30-foot waterway through the divides between the St. Lawrence and Lake Champlain and between Lake Champlain and the Hudson River, and to the large dimension of prism required on the 21-foot Mohawk waterway to carry the flood discharge of the river.

In order to determine the probable speed which can be maintained by steamships on the proposed deep waterway, the Board has collected, as far as possible, all the available data relative to the performance of steamers on the lakes and connecting channels and on the waterways of Europe, and has utilized the results to verify the theoretical deductions derived in the discussion of the speed of ships in Appendix No. 4.

## DIMENSIONS OF STRUCTURES.

The dimensions of lock structures have been designed with reference to the type carrier likely to use the waterway, and to the importance of the amount of time required to pass a ship through the waterway in relation to the number of ships which can be passed through a lock in a given time. The time which will be consumed by a vessel in locking through the system will depend upon the number of locks

and the time required at each, while the number which can be passed per day will depend upon the average time required for lockage.

It is therefore evident that with high lifts and less number of locks the time between terminals will be diminished and the annual traffic capacity decreased.

In view of the fact that the increase of detention at large locks only amounts to the additional time required to fill the lock chamber, the Board is of the opinion that the advantages to be derived from quick time of transit through the waterways, and from developing shipbuilding industries on the lakes, is of more importance than a small decrease in traffic capacity.

In this connection it may be noted that the sailing time between the upper lake ports and the seaboard is less than the running time required by freight trains between the same terminals.

The dimensions of lock structures which will best subserve the traffic of the waterway and the design of the lock gates best adapted for operating the locks have been investigated under the direction of the Board by specialists in such construction, the results of which are fully discussed in Appendixes Nos. 1 and 2.

The single locks which have been designed for a 30-foot waterway are to be 740 feet long, 80 feet wide, and have lifts to conform with the present development of water power on the routes. Where flights of locks are necessary, a duplicate set is provided, having a width of 60 feet. For a 21-foot waterway, the locks, whether single or double, are to be 600 feet long, 60 feet wide, and have lifts the same as in the 30-foot waterway. Consideration has been given to the advisability of making the locks of the 21-foot waterway 80 feet wide, for the purpose of floating large ships, light, from the lake shipyards to the seaboard.

At the Lewiston escarpment, at the Long Sault Rapids, on the St. Lawrence, and at Champlain the natural conditions are such as to make lifts of from 40 feet to 50 feet desirable.

From the results of the investigation of lock gates, discussed in Appendix No. 2, it appears that steel double-leaf mitering gates, with horizontal girder frames, fulfill the requirements for wide locks with high lifts, and this type of gate has been made the basis for designs and estimates.

### DAMS AND SLUICES.

The dams for the Mohawk and Hudson rivers have been designed with as great a length as the natural conditions will permit, for the purpose of making the range in stage from high to low water as small as possible. This range can be still further reduced at some of the dams by the use of movable crests on the dams for holding up the level of the pools during periods of low water.

At locations where long dams are not desirable sluice gates of the

Stoney type are provided, for the purpose of maintaining full control of the river discharge. With four exceptions, all the dams can be constructed on rock foundations. At the locations where rock is not available for foundations the heads on the dams will be small, making it easy to construct safe structures.

### BREAKWATERS.

At the Olcott and Oswego terminals of the Niagara Ship Canal and of the Oswego-Mohawk route artificial harbors protected by breakwaters will be necessary. A careful study has been made of the type of breakwater best adapted to the conditions at these harbors, and the result of the investigations are given in Appendix No. 3.

### CORNELL EXPERIMENTS.

In the investigations to determine the volume of discharge of the Oswego, Mohawk, and Hudson rivers it became apparent from the start that the existing data relative to the flow of water over dams were inadequate to determine the discharge where the depth on the crest of the dam was much over 1.5 feet.

The uncertainty as to the value of the coefficient of the weir formula which should be used for dams of different cross sections and for different depths on the crests made it evident that additional investigations would be necessary before satisfactory estimates could be made of the value of water-power rights, which may be modified, or of the amount of slope walls and bank protection which would be needed between the limits of the high and low water stages of the proposed waterway.

In the fall of 1898 the experiments of H. Bazin, published in the Annales des Ponts et Chaussées became available and established the coefficients for a great variety of different shaped weirs, but, unfortunately, for depths of less than 1.5 feet on the crests. Through the courtesy of Prof. A. E. Fuertes, director of the College of Civil Engineering of Cornell University, the hydraulic laboratory of that institution was placed at the disposal of the Board, and Prof. Gardner S. Williams, engineer in charge, in cooperation with Mr. G. W. Rafter, acting for the Board, made an extensive series of observations to extend the coefficients of the Bazin formula up to depths of 5 feet on the crest of dams having cross sections similar to those on the Mohawk and Hudson rivers. The results of these observations are fully discussed in Appendix No. 16.

### BRIDGES.

The railroad and highway bridges for crossing the waterways are designed for 250 feet clear openings on the 30-foot channel and 240 feet on the 21-foot channel. At most of the crossings either swing or bascule bridges will be required, but in the case of the New York

Central Railroad crossing near Utica it will be necessary to change the grade of the railroad for a considerable distance and cross the waterway with a fixed span. In a few cases of highway crossings, where the traffic is light, steam ferries have been provided for instead of swing bridges.

## UNIT PRICES.

In establishing unit prices for estimates the Board has carefully considered the prices paid on the large works throughout the country involving similar construction, and has secured the advice and opinions of some of the most experienced contracting engineers in this class of work. It is the opinion of the Board that the prices used fairly represent the average cost which will be required to construct the different divisions of the waterways under normal conditions of doing work.

## CONTROL OF LAKE ERIE.

The investigation of the subject of lake regulation has occupied the attention of the Board since its first organization in 1897, and a preliminary report embodying the results and conclusions was submitted in December, 1899, and printed in House Doc. No. 200, Fifty-sixth Congress, first session.

It was the intention of the Board to give the results of its investigations on the subject in its complete report on deep waterways, and the discussion has therefore been embodied in the report as Appendix No. 6.

The regulating works in connection with a ship canal from Lake Erie to Lake Ontario form a complete project of improvement without the lock and canal around the rapids at the head of Niagara River, provided for in the preliminary report, which has been omitted from the accompanying estimates.

Under the influence of varying relative supply, evaporation, and discharge, the monthly mean level of Lake Erie has had an extreme variation of 4.6 feet during the past seventy years. The low level generally occurs at a time of year when navigation is most active. If the level of the lake could be constantly maintained at or near a high stage, navigation would be greatly benefited by securing a maximum depth at the time when it is most needed and by the practical deepening of the lake harbors.

To maintain the level of a lake at or near some fixed stage, the discharge must be controlled so that it will always be approximately equal to the difference between the supply of water to the lake and the evaporation from its surface. In the case of Lake Erie this can only be accomplished by establishing regulating works in or near the discharging waterway. These works must be so arranged that they will not only maintain the level of the lake at or near the fixed stage adopted, but also so that they will produce no injurious effects upon

the lakes and waterways from which a part of the supply is derived or upon those which receive the discharge.

This is the problem which the Board has investigated. For the details of its investigation, the methods employed, the data and reasoning upon which they are based, and the results obtained, the Board refers to the paper on Lake Regulation, by Mr. George Y. Wisner, member of the Board, which is appended to this report. This paper was prepared by Mr. Wisner in consultation with the other members of the Board, and it fully expresses their views. In this report, therefore, it is only necessary to give a brief statement of the conclusions at which the Board has arrived.

### REGULATING WORKS.

The Board is of the opinion that the best location for works for regulating the level of Lake Erie is at the foot of the lake, just below Buffalo Harbor. The location in the Niagara River below Tonawanda has been advocated, but the Board finds upon investigation that regulation by works at this point would be less effective and much more expensive than at the adopted location.

The works projected by the Board are designed to distribute the discharge of the lake so as to reduce its variation of level to a small amount. The result can not be attained by the use of submerged fixed weirs only, and a series of sluices is added to secure, in combination with fixed weirs, the control desired. The weirs will be constructed of concrete blocks and will have an aggregate length of 2,900 feet. The sluices, 13 in number, of the Stoney type, will each have an opening of 80 feet, making an aggregate of 1,040 feet. The piers separating the sluice openings will be of substantial, first-class masonry. The sluices can be operated under rules easily formulated, and, in the opinion of the Board, amply provide for conditions more unfavorable than any recorded.

The location of these works and the details of their design are shown on plates 84, 85, 86, and 87. Their estimated cost is $796,923.

### EFFECT UPON LAKE ERIE.

The extreme high-water stage of Lake Erie is about 575 feet above tide water. The level adopted by the Board for regulation is 574.5 feet, or about 0.5 foot below the level of extreme high water. This is the lowest elevation at which regulation can be effected without enlarging the cross section of the river at the gorge. Should it, for any reason, be considered desirable to regulate the lake at a lower level, the desired result can be accomplished by enlarging the cross section of the river so as to provide for the maximum discharge at the adopted level.

The Board is of the opinion that with the works proposed the level of the lake can be maintained during the season of navigation within

about 0.6 foot below the level adopted for regulation, under all conditions of supply heretofore recorded. Considerable changes of level due to violent winds would be temporary and infrequent, and, in the opinion of the Board, would not seriously interfere with the regulation of the lake level.

### EFFECT ON THE NIAGARA RIVER.

The current velocities in the Niagara River, below the point where the canal enters it, will not be increased by the operation of the regulating works.

### EFFECT ON LAKE ONTARIO.

The modification of the outflow of Lake Erie proposed for the regulation of its level will not materially change the total volume of annual discharge, and will amount to only about one-fifth of the variation of the discharge for different years under present conditions. The effect of this modification upon Lake Ontario will be to slightly increase the rate of rise in the spring and make the date of maximum stage a little earlier. This will not injure the navigation interests of the lake.

### EFFECT ON THE ST. LAWRENCE RIVER.

The Board regrets that it has been unable to obtain reliable data connecting the discharge of the St. Lawrence River with the varying levels of Lake Ontario. The modification of the flow of the Niagara River which will be produced by the proposed regulating works is so small, when compared with other causes of change of level, that the Board is of the opinion that it can not affect the depths of the waterways receiving the discharge to any material extent.

The effect of the regulation of the level of Lake Erie herein proposed would be to diminish the slopes of the Detroit and St. Clair rivers for any given volume of discharge and to redistribute the flow. In the opinion of the Board, the result of these changes would be to raise the low-water stage about 3 feet in Lake Erie, 2 feet in Lake St. Clair, and 1 foot in Lake Huron. This would obviously be of great benefit to navigation.

If the channel from Lake Huron to Lake Erie should be made 30 feet deep the low-water plane would be slightly lower, the difference in level probably not exceeding 0.3 foot.

### CONCLUSION.

The Board is of the opinion that works can be established for regulating the level of Lake Erie which will be of great value to navigation, not only in Lake Erie, but also in the upper lakes and connecting waterways, and will be of no injury to the lower waterways of the lake system, and that such works can be constructed at a cost which will be small compared with their benefit to commerce.

In arriving at these conclusions the Board has utilized all the information it has been able to obtain within the period covering its investigations. Additional observations are needed for more precise determinations of the probable effects of regulation upon the levels of the St. Clair, Detroit, and St. Lawrence rivers, and the probable conditions of flow from the upper lakes. The Board is, however, of the opinion that the uncertainties arising from this lack of complete data are fully covered by the ample provision made for varying the discharge at the regulating works.

Attention is invited to the fact that the project is of international character, and can only be carried out after agreement between the United States and Canadian Governments.

## NIAGARA SHIP CANAL.

The project for a waterway from the lakes to the Atlantic suitable for transporting the commerce of the upper lakes has prominently attracted public attention for nearly a century, during which time the citizens of New York have maintained that such waterway must be built directly across the State, as an aid in building up the financial and commercial supremacy of New York City, while the people farther west have insisted that the canal should be constructed on the route best adapted for transporting the commerce of the country tributary to the lakes.

In 1812 the governor and judges of the Territory of Michigan resolved unanimously "that in their opinion the canal contemplated by the commissioners of internal navigation in the State of New York from Black Rock to Rome would not be so desirable as a canal around the cataract of Niagara and another by the falls of Oswego." In regard to which the New York commissioners reported that "they had too much respect for these gentlemen to suppose they would have given their opinion without information and consideration, and therefore must infer that the information received was not founded in fact, or that, not having habitually turned their attention to objects of this sort, they were not so well qualified to judge as the consciousness of intelligence respecting matters more familiar to their minds may have led them to suppose."

It was then, and is still, openly admitted that the St. Lawrence River is the natural outlet and the line of least resistance for a waterway from the Great Lakes to tide water, but that for New York State to permit such canal to be built would be to commit commercial suicide.

The advocates of this theory have left out of consideration the fact that the larger portion of the commerce between the lakes and tide water is of a domestic nature and that the only benefits to be derived from export traffic through a port are those from levying tribute on the foreign commerce of a neighboring State.

It is an established fact that a waterway of sufficient capacity to

transport the tonnage of the lakes to the sea can be constructed via Lake Ontario for less cost than by any other route, and that a steamer will traverse it in about three-quarters the time required on a direct waterway of similar dimensions from Lake Erie to the Mohawk at Utica. If, therefore, the object desired is to develop a waterway which will best subserve the interests of the lake commerce, it is apparent that the route should be through Lake Ontario and that a ship canal from Lake Erie to Lake Ontario should be an essential part of it.

### PHYSICAL CHARACTERISTICS OF ROUTE.

The physical conditions and the obstacles to be overcome in constructing a waterway from Lake Erie to Lake Ontario are similar for all of the proposed routes.

From Lake Erie to the proposed site for Lock No. 1 the canal prism will have to be excavated through a limestone ridge, with the surface of rock varying from 10 feet to 21 feet below mean level of the lake.

From Lock No. 1 to Tonawanda the prism of the waterway, where below bottom of the river, will be through sand and gravel except opposite Strawberry Island, where rock is found above grade.

From Tonawanda to Lasalle the surface of the shale ridge is from 10 feet to 20 feet below the low-water level of the river. The land gradually rises from the river to the top of the escarpment, extending from above Lewiston to Lockport, with an average elevation of about 620 feet above mean tide at New York.

A little west of Lockport a narrow ravine, known as the "Gulf," cuts through the escarpment, which has been generally regarded as the best location for locking down to the lower plateau. Comparative estimates, based on accurate surveys, indicate that a better line can be located west of the "Gulf," on which the waterway can be constructed at less cost.

From the foot of the escarpment at Lockport the plateau, consisting of red shale, gradually falls toward Lake Ontario.

The top of the escarpment above Lewiston has practically the same elevation as at Lockport, but has a steeper incline toward Lake Ontario than the latter. The construction of a waterway by either route will involve the construction of locks having high lifts.

On the Lewiston route the Niagara River constitutes a first-class natural harbor for the Lake Ontario terminal, whereas for all the other routes shown on plate 92 artificial harbors will have to be constructed.

The total fall from the plane of the proposed regulated stage of Lake Erie to that of standard low water in Lake Ontario is 330 feet.

The plane of standard low water is that adopted in the report of the Deep Waterway Commission of 1896, and is that stage "at or below which monthly mean water has stood not more than an aggregate of

ten months during the season of navigation out of the aggregate of 18 lowest monthly mean waters occurring between 1860 and 1895."

## FORMER SURVEYS AND EXAMINATIONS.

Five surveys and 10 different estimates have been made for an American canal from Lake Erie to Lake Ontario, in seven of which two different routes have been considered, one from Niagara River above the falls to Lewiston, and thence by the Niagara River to Lake Ontario; and the other from Tonawanda to Lake Ontario at Olcott. All these surveys and estimates contemplated the use of Niagara River from Lake Erie to the entrance of the canal as a part of the route, but as the natural low-water depth at the head of the river is only 17 feet, mean stage, any greater depth of water would necessitate the deepening of the outlet of the lake or a canal around the rapids. Since to deepen the outlet would lower the general level of Lake Erie, a canal around the rapids is the only method by which a deep waterway can be constructed without reducing the depths of lake, harbors, and channels.

The estimate of $23,617,900 made in 1889 for a waterway 100 feet wide and 20.5 feet deep from Tonawanda to Olcott, did not include anything for the improvement of the head of the river, and therefore does not constitute a complete project for a deep waterway between Lakes Erie and Ontario. All comparative surveys indicate that the route via Lewiston and Niagara River could be constructed at less cost than any of the lines direct to Lake Ontario, but for various reasons the route from Tonawanda to Lake Ontario at Olcott has generally been preferred.

The basis on which the comparative merits of the two routes should be established is the relative cost of construction and annual maintenance of the respective waterways, and the time required by a type carrier of given speed, in open water, to pass over the waterways between points common to both lines.

## DEEP WATERWAY SURVEY.

A party was organized under the direction of the Board by Mr. C. L. Harrison, C. E., in September, 1897, for making surveys and examinations for developing projects for 21-foot and 30-foot waterways between Lake Erie and Lake Ontario. The topography of the country was determined with reference to developing contours at 2-foot intervals on the final maps. All buildings, fences, roads, creeks, culverts, bridges, timber land, and railroads were located, and the width, depth, cross section, and volume of flow of streams for high, low, and medium stages determined wherever possible.

Borings were made at such intervals and depths as were necessary to determine the elevation of the surface of rock, where above grade, and the kind of material to be excavated, and a sufficient number of

diamond-drill holes were bored to establish the strike and dip of the rock strata, the nature of the rock to be excavated, and the character of foundations where structures were to be located.

The routes and limits of the section of country to be covered by the surveys were fixed by a reconnoissance made by the Board.

The two routes investigated commence at deep water in Lake Erie, off the entrance to Buffalo Harbor, and running through Black Rock Harbor to near the head of Squaw Island; lock down to the level of the river below the rapids, and then follow the general course of the river to Tonawanda and Cayuga Island, at which points, respectively, the two waterways leave the river.

### LASALLE-LEWISTON ROUTE.

This route starts from Lake Erie at an elevation corresponding to the proposed regulated stage for the lake[1] (574.5 feet) and, locking down into the river below the rapids on the same line as the Tonawanda-Olcott route, continues down the river to the head of Cayuga Island, and thence on a tangent, with a low-water level of 563.5 feet, to within a half mile of the foot of Lock No. 2, at the head of the escarpment above Lewiston. From the top of the escarpment the route passes down the bluff to the Niagara about a half mile below Lewiston, with 6 double locks of 40 feet lift each and 2 double locks of 39.4 feet lift each. The fall of the river from the foot of Lock No. 9 to Lake Ontario (6 miles) is about 0.2 foot, making the total lockage and slope from Lake Erie to Lake Ontario 330 feet.

The elevation of the top of the ridge above Lewiston at the point of maximum cutting is 620 feet above tide water, or 56.5 feet above the proposed low-water surface of the canal, and for a distance of 6 miles the prism of the waterway is entirely in rock.

### MATERIAL TO BE EXCAVATED.

From deep water in Lake Erie to the foot of Lock No. 1, at the head of Squaw Island, 1.8 miles below site of the regulating work, there is a ridge of hard limestone almost entirely bare, except in Black Rock Harbor, where it is covered with sand, gravel, and clay. Below Lock No. 1 the rock drops below grade, and, with the exception of about a mile opposite Strawberry and Frog islands, does not interfere with 30-foot navigation of the river above Tonawanda.

From Tonawanda to Lasalle, about 4 miles, rock composed of Salina shales is from 10 feet to 20 feet below water level, and from Lasalle to the escarpment above Lewiston (7.5 miles) the excavation will be in Niagara limestone overlaid with clay, sand, and gravel.

The excavation for the six double locks down the escarpment will be through limestone, sandstone, and shales, and from the foot of

[1] Estimates have been made for level of Lake Erie regulated and for standard low stage of the lakes.

this flight to the Niagara River the cutting will be in shales covered to about one-half the depth of the cut with sand, gravel, clay, and bowlders.

Five diamond-drill holes were put down along the alignment of the proposed route to determine the character of the material to be excavated and the nature of the foundations where structures are to be located.

The limestone, sandstone, and shales between Niagara River and the foot of Lock No. 7 will probably cost about the same per cubic yard to excavate, but from Lock No. 7 to the lower end of the canal the rock is a soft shale and can be taken out for about three-fourths the unit price for excavating limestone.

From the lower end of the canal to Lake Ontario (6 miles) the river is from 40 feet to 60 feet deep and forms one of the finest harbors on the Lakes. The bar in Lake Ontario outside of the entrance to the river has a depth on its crest of 24 feet at standard low water, and is composed of sand and gravel.

### STREAMS CROSSED.

Three small streams, Cayuga Creek, Gill Creek, and Fish Creek, are intersected by the proposed waterway. These streams have little or no flow during dry periods, but at times of high water they carry the drainage of about 63 square miles of adjacent country. Provision has been made for taking the discharge of these creeks into the canal over the crests of long weirs.

Six miles of double-track and 3 miles of single-track railroad will have to be relocated and constructed, and four railroad swing bridges and one railroad fixed bridge provided for crossing the waterway and also three highway swing bridges and one steam ferry for the accommodation of highway traffic.

Power for operating the locks and lighting the waterway may be developed by taking water in pipes from the canal above Lock No. 2 and carrying it to a power house opposite Lock No. 7, from the wheel pit of which the water can be wasted through a tailrace into the river.

By this arrangement Locks Nos. 2, 3, 4, 5, 6, and 7 can be drained directly into the river, thus avoiding all pumping plant for the main flight of locks down the escarpment. Lock No. 8 can be drained when necessary into Lock No. 9, but, as the canal prism below the latter is lower than the river, a pumping plant will have to be provided for emptying it for making repairs.

### MATERIALS FOR CONSTRUCTION.

All the stone necessary for retaining walls, slope walls, back fill, and concrete may be obtained from the excavation between Cayuga Island and the top of the escarpment, but sand will probably have to be brought to the works from either Lake Erie or Lake Ontario.

The total length of the waterway from the site of the proposed regulating works at the foot of Lake Erie to Lake Ontario is 30.5 miles, of which 18.9 miles is river channel, 600 feet or more in width, and 11.6 miles of the adopted standard canal section.

The plans for structures are shown on plates 68 and 69.

*Estimates for 30-foot channel.*

| | |
|---|---|
| **Lake Erie regulated:** | |
| Excavation | $42,335,142 |
| Retaining walls, slope walls, and back fill | 1,640,928 |
| Railroad changes | 363,424 |
| Right of way | 1,185,050 |
| Bridges and ferries | 1,212,532 |
| Cribs at lock approaches | 210,599 |
| Locks | 18,437,004 |
| Operating plant | 600,000 |
| Buffalo waterworks tunnel | 30,000 |
| Entrance of streams | 20,255 |
| Regulating works | 796,923 |
| | 66,831,857 |
| Engineering, superintendence, and contingencies, 10 per cent[1] | 6,603,493 |
| Total | 73,435,350 |
| **Standard low water:** | |
| Excavation | 44,552,322 |
| Retaining walls, slope walls, and back fill | 1,640,928 |
| Railroad changes | 363,424 |
| Right of way | 1,185,050 |
| Bridges and ferries | 1,212,532 |
| Cribs at lock approaches | 210,599 |
| Locks | 18,443,484 |
| Operating plant | 600,000 |
| Buffalo waterworks tunnel | 30,000 |
| Entrance of streams | 20,255 |
| | 68,258,594 |
| Engineering, superintendence, and contingencies, 10 per cent | 6,825,859 |
| Total | 75,084,453 |

*Estimates for 21-foot channel.*

| | |
|---|---|
| **Lake Erie regulated:** | |
| Excavation | $20,615,492 |
| Retaining walls, slope walls, and back fill | 1,281,985 |
| Railroad changes | 363,424 |
| Right of way | 1,185,050 |
| Bridges and ferries | 1,129,403 |
| Cribs at lock approaches | 294,995 |
| Locks | 12,294,196 |
| Operating plant | 600,000 |
| Entrance of streams | 20,255 |

[1] The estimate for regulating works already contains cost of engineering, superintendence, and contingencies.

| | |
|---|---|
| Lake Erie regulated—Continued. | |
| Buffalo waterworks tunnel | $30,000 |
| Regulating works | 796,923 |
| | 38,611,723 |
| Engineering, superintendence, and contingencies, 10 per cent[1] | 3,781,480 |
| Total | 42,393,203 |
| Standard low water: | |
| Excavation | $22,079,979 |
| Retaining walls, slope walls, and back fill | 1,281,985 |
| Railroad changes | 363,424 |
| Right of way | 1,185,050 |
| Bridges and ferries | 1,129,403 |
| Cribs and lock approaches | 294,995 |
| Operating plant | 600,000 |
| Lock | 12,300,676 |
| Entrance of streams | 20,255 |
| Buffalo waterworks tunnel | 30,000 |
| | 39,285,767 |
| Engineering, superintendence, and contingencies, 10 per cent | 3,928,577 |
| Total | 43,214,344 |

## THE TONAWANDA-OLCOTT ROUTE.

This route follows the same line as the Lasalle-Lewiston route from Lake Erie to Tonawanda, at which place it leaves the Niagara River at the head of Tonawanda Island, with an elevation of 565 feet above tide water at New York for low stage of the river,[2] and continues at that level 13.2 miles to the head of the escarpment west of Lockport, where the ridge to be cut through has an elevation of 636 feet above tide water, or 71 feet above the water surface in the canal. From the top of the escarpment the line descends to Lake Ontario, 11.2 miles, with two single and three double locks of 40 feet lift each, one single lock with 30.5 feet lift, and three double locks each with 30 feet lift.

At a distance about 1 mile above Lake Ontario the line enters the gorge of Eighteenmile Creek and follows it to the lake.

The proposed harbor at Olcott consists in widening Eighteenmile Creek to the width of 400 feet from the last lock of the canal to the lake, and protecting the entrance by breakwaters, as shown on figures

[1] The estimate for regulating works already contains cost of engineering, etc.

[2] All elevations for the survey of the Niagara ship canal are referred to the bench mark established by the United States engineers on the light-house at Buffalo, of which the elevation is given as 589.807 feet above mean tide at New York.

The difference in level of the United States bench marks at Greenbush and Oswego has been redetermined by the parties making the deep-waterway survey, but as there is some doubt as to the correct difference of level between Greenbush and tide water and between the Oswego and Buffalo bench marks, it has been deemed advisable to adopt the plane of reference used in previous reports.

7 to 12, inclusive, Appendix No. 3. The lake in front of the canal entrance is shallow, with a shale rock bottom, which will have to be excavated for a width of 600 feet and for the required depth.

Three diamond-drill holes were put down near the top of the escarpment to determine the strike, dip, and elevation of the different kinds of rock strata which would be cut by the excavation for the waterway.

The strike of the rock is approximately parallel to the top of the ridge extending toward Lewiston and has a dip to the south of about 5.6 feet per 1,000 feet.

### MATERIALS TO BE EXCAVATED.

Between Buffalo and the escarpment at Lockport the rock, where above bottom grade of the waterway, is composed of either limestone or Niagara shale, overlaid with silt, sand, gravel, clay, or hardpan. From Lock No. 2, at head of the escarpment, to the foot of Lock No. 5, the excavation will be through limestone, sandstone, and shale, and from Lock No. 5 to Lake Ontario the prism of the canal will be through soft red shale, overlaid with sand, gravel, clay, or hardpan, for about one-half the depth of the cut. (For details of these materials see Appendix No. 18.) The limestone and Niagara shale south of the escarpment will probably cost about the same per cubic yard to excavate, and, for similar conditions, the red shale between the escarpment and Lake Ontario can be taken out for about three-quarters of the unit price for excavating the limestone.

### STRUCTURES.

The locks designed and estimated are to be of the standard type shown on plates 68 and 69, and described in Appendix No. 1.

A plant for generating power by electricity or compressed air for lighting and operating the canal from Lock No. 2 to Lake Ontario may be installed by taking water from the canal above Lock No. 2 and leading it through a tunnel and pipes to a power house near the bottom of the "Gulf," about 1,200 feet east of Station 1290, and using the "Gulf" and Eighteen-Mile Creek for a tail race. At Lock No. 1 and vicinity, power for lighting the canal and operating gates, valves, and pumps may be generated near the lock site or obtained by lease from the power companies at Niagara Falls.

All railroad and highway bridges are estimated for a clear opening of 250 feet between piers, for the standard types described elsewhere, and for the locations given in the report of the assistant engineer in charge of the survey. (Appendix No. 10.)

Stone retaining walls, slope walls, and concrete may be obtained from the excavations, but sand will probably have to be brought from either Lake Erie or Lake Ontario.

The total length of waterway from the proposed regulating works at

the foot of Lake Erie to the shore of Lake Ontario at Olcott is 35.9 miles, of which 9.9 miles is improved river channel and 26 miles is of standard canal section.

*Estimates for 30-foot channel.*

| | |
|---|---|
| Lake Erie regulated: | |
| Excavation | $39,572,525 |
| Retaining walls, slope walls, and back fills | 3,917,583 |
| Embankment | 94,853 |
| Railroad changes | 199,640 |
| Diversion of streams | 68,943 |
| Right of way | 2,254,835 |
| Bridges and ferries | 2,072,190 |
| By-passes | 39,585 |
| Locks | 17,553,779 |
| Cribs at lock approaches | 888,932 |
| Operating plant | 700,000 |
| Olcott Harbor | 584,705 |
| Regulating works | 796,923 |
| Buffalo waterworks tunnel | 30,000 |
| | 68,747,493 |
| Engineering, superintendence, and contingencies, 10 per cent[1] | 6,797,757 |
| Total | 75,572,250 |
| Standard low water: | |
| Excavation | 41,789,705 |
| Retaining walls, slope walls, and back fill | 3,917,583 |
| Embankment | 94,853 |
| Railroad changes | 199,640 |
| Diversion of streams | 68,943 |
| Right of way | 2,254,835 |
| Bridges and ferries | 2,072,190 |
| By-passes | 39,585 |
| Locks | 17,560,259 |
| Cribs at lock approaches | 888,932 |
| Lock operating plant | 700,000 |
| Olcott Harbor | 584,705 |
| Buffalo waterworks tunnel | 30,000 |
| | 70,201,230 |
| Engineering, superintendence, and contingencies, 10 per cent | 7,020,123 |
| Total | 77,221,353 |

*Estimates for 21-foot channel.*

| | |
|---|---|
| Lake Erie regulated: | |
| Excavation | $22,213,215 |
| Retaining walls, slope, and back fill | 3,126,243 |
| Embankment | 85,635 |
| Railroad changes | 199,640 |
| Diversion of streams | 68,943 |
| Right of way | 2,254,835 |

[1] Estimate for regulating works already contains cost of engineering, superintendence, and contingencies.

| | |
|---|---|
| **Lake Erie regulated—Continued.** | |
| Bridges and ferries | $1,919,240 |
| By-passes | 39,585 |
| Locks | 11,600,601 |
| Cribs at lock approaches | 790,120 |
| Lock-operating machinery | 700,000 |
| Olcott Harbor | 296,334 |
| Buffalo regulating works | 796,923 |
| Buffalo waterworks tunnel | 30,000 |
| | 44,121,314 |
| Engineering, superintendence, and contingencies, 10 per cent[1] | 4,332,439 |
| Total | 48,453,753 |
| **Standard low water:** | |
| Excavation | 23,677,702 |
| Retaining walls, slope, and back fill | 3,126,243 |
| Embankment | 85,635 |
| Railroad changes | 199,640 |
| Diversion of streams | 68,943 |
| Right of way | 2,254,835 |
| Bridges and ferries | 1,919,240 |
| By-passes | 39,585 |
| Locks | 11,607,081 |
| Cribs at lock approaches | 790,120 |
| Lock-operating plant | 700,000 |
| Olcott Harbor | 296,334 |
| Buffalo waterworks tunnel | 30,000 |
| | 44,795,358 |
| Engineering, superintendence, and contingencies, 10 per cent | 4,479,536 |
| Total | 49,274,894 |

## RELATIVE VALUE OF ROUTES.

Referring to the above estimates for the Tonawanda-Olcott route it will be noted that it exceeds the estimated cost of the Lasalle-Lewiston route by $6,060,550 for a 21-foot channel and $2,136,900 for a 30-foot channel.

Following the method developed in Appendix No. 4, on speed of ships in the proposed deep waterway, it is found that a steamship of 19 feet draft in the 21-foot channel would consume one hour and nine minutes more time between Buffalo and a point common to the two routes in Lake Ontario in traversing the Tonawanda-Olcott waterway than by the Lasalle-Lewiston route, and that in a 30-foot channel a steamship of 27-feet draft would be one hour and forty-three minutes longer by the Tonawanda route.

Since the cost of maintenance of the Lewiston waterway would be less than for the route from Tonawanda to Olcott, the interest and

[1] Estimate for regulating works already contains cost of engineering, superintendence, and contingencies.

expense account will be much less for the former, and as the actual time saved by a steamship on the Lewiston route would be from 11 to 16 per cent of the time of passage, it is evident that both economy in construction and cost of transportation definitely determine the Lewiston waterway as the preferable route.

In the discussion of deep-waterway routes to the sea in this report, whatever route out of Lake Ontario may be considered, all estimates of cost of construction, transportation, and times of passage for ships of different speeds and dimensions will be based on the use of the Lasalle-Lewiston route.

## OSWEGO-MOHAWK ROUTE.

The development of a project for a deep waterway from Lake Ontario to the Hudson via the Oswego and Mohawk rivers is complicated with more difficult conditions than any other part of the proposed route from the lakes to the sea. Not only must a channel be located which may be easily and safely navigated, but water must be furnished during dry periods with which to float and lock ships through the waterway, the river channels must be canalized and rectified so as to carry the flood waters at times of high stages without injury to the banks or delay to navigation, and the manufacturing enterprises depending upon the water power at the various dam sites must have their water privileges interfered with the least possible.

### PHYSICAL CHARACTERISTICS OF ROUTE.

The Oswego River from Lake Ontario to Fulton, where the line leaves the river, is a series of rapids over sandstone reefs, and has an average fall of over 8 feet per mile. The divide between the Oswego River at Fulton and Oneida Lake consists of extensive swamps between sand ridges rising 20 feet to 50 feet above the level of the lake.

East of Oneida Lake the land gradually rises to the vicinity of Rome, where it has an elevation of about 430 feet above tide water, and 64 feet above the level proposed for this improved low-water stage of Oneida Lake.

From Rome to Frankfort the profile of the Mohawk Valley has a very even slope to the east, and at the latter place has about the same elevation as the low-water surface of Oneida Lake. Between Frankfort and Schenectady the numerous streams tributary to the river increase the flood discharge to such an extent that any waterway designed for safe navigation and to carry the river discharge without erosion of the banks must have a gradually increasing cross section downstream.

Below the bend of the river known as "Little Nose," about 6 miles above Fultonville, the volume of flow at times of high water is such that an economical cross section for carrying the discharge at a

velocity of less than 4 feet per second becomes practically the same for 21-foot and 30-foot waterways.

From Schenectady to the Hudson the line crosses the divide between the rivers at South Schenectady and then locks down the valley of Normans Kill.

The surveys and investigations were made by three different field parties, viz: One under the direction of Mr. A. J. Himes, assistant engineer, on the work of the western division between Oswego and Herkimer; another, under the charge of Mr. D. J. Howell, assistant engineer, on the survey of the eastern division between Herkimer and the Hudson, and a party under the direction of Mr. George W. Rafter, C. E., organized to investigate and report on the sources and quantity of available water supply for the waterway.

The results of the investigations of these different parties, while complete in themselves, must be regarded as constituting a single project.

The investigations at the start contemplated the improvement of the Oswego River by locks and dams from Oswego to Phoenix, and a similar improvement of the Mohawk River from Utica to the Hudson, with a ship canal connecting the upper terminals of these canalized streams. During the progress of the work, however, it became apparent that deviations could be made near Oswego, Fulton, and Schenectady whereby about $25,000,000 could be saved in the cost of construction and the waterway shortened several miles, leaving the principal water-power privileges undisturbed.

Two different projects for the connecting waterway from the Oswego to the Mohawk have been examined—one for a summit level at an elevation of 416 feet above tide water, with a water supply to be carried through a feeder from reservoirs on the Black and Salmon rivers, and the other with a summit level the same as that of Oneida Lake—379 feet above tide water at New York.

In the latter case, Oneida Lake is to be used for a storage reservoir, but during excessive dry seasons an additional supply will probably be needed, for which provision has been made by locating a reservoir in the Salmon River Valley with a connecting feeder from the reservoir to the waterway, as shown on plate 93.

## WESTERN DIVISION.

The line leaves Lake Ontario from an artificial harbor formed by two breakwaters to be constructed about 1 mile west of the mouth of the Oswego River, and passes through the westerly limits of the city along a narrow valley, rising 85.6 feet in a distance of 5.7 miles, to a dam above the town of Minetto, where the waterway joins the river, which difference in level it is proposed to overcome with four locks of 21.4 feet lift each.

These locks are to consist of one single lock at the harbor terminal

of the canal, two double locks in flight, about 4,000 feet from the lake, and a single lock in the head of the canal where it leaves the Oswego River near Minetto.

From Minetto the line follows the river 4.9 miles to the northern side of the village of Fulton, where it enters the valley of a small creek and continues across the swamp and sand ridges between the river and Oneida Lake. At the point of deepest cutting through the sand ridge the banks will be 54 feet above water surface at low stage.

For a waterway having a high summit level across the divide between the lake and the Mohawk River it is proposed to establish the low water of the lake at an elevation of 376 feet, and for the project having the lake for summit level at an elevation of 379 feet.

In the first of these projects it is proposed to overcome the 45-foot rise from the Oswego River at Fulton to Oneida Lake with two locks of 22.5 feet lift each, and in the latter to have two locks of 18 feet lift each, and one with lift varying from 12 to 19 feet, according to the stage of water in Oneida Lake.

Oneida Lake is 21 miles long, 14 miles of which is over 30 feet deep, and has an area of 77 square miles at the natural low-water stage of 371 feet, which will be increased to 149 square miles, with the reservoir full at an elevation of 386 feet.

*High-level project.*—The summit of the divide near Rome is about 430 feet above mean tide at New York, which for the high-level project is crossed with a water-surface elevation of 416 feet. The summit level will be 13.6 miles long and will receive water supply from the Black River feeder near its western end, 3 miles west of Rome.

West of Rome the line from Oneida Lake follows the line of greatest depression of underlying rock, and, after crossing the divide, intersects the present channel of the Mohawk River several times, but as the stream is small compared with the proposed section of the waterway, the entire drainage would be diverted into the new channel. The eastern end of the summit level for the high-level project is about a mile below the mouth of the Oriskany Creek, and at times of floods in the Mohawk Valley 10,000 cubic feet per second of the Mohawk discharge may be turned westward through the canal to Oneida Lake and used for storage or wasted down the Oneida and Oswego rivers to Lake Ontario.

Investigation of floods in the Mohawk Valley indicates that in extreme cases the discharge at Little Falls may reach about 45,000 cubic feet per second, and by diverting a portion of the flood volume westward a much safer and less expensive channel may be constructed between Utica and Albany. By-passes and regulating sluices are provided for at each end of the summit level for controlling the volume of flow in each direction at times of floods and to furnish a low-water flow in the Mohawk equal to that under natural conditions.

The summit level will vary in elevation from 376 feet to 378 feet

above mean tide at New York, depending on the depth of storage in Oneida Lake.

It is proposed to control the stage of Oneida Lake by means of a movable dam 300 feet long in connection with regulating sluice gates capable of passing 10,000 cubic feet of water per second when fully open.

*Low-level project.*—By converting Oneida Lake into a storage reservoir and cutting a channel through the Rome divide, navigation at lake level may be extended to the Mohawk at Frankfort, a distance of 72.1 miles from the lock at western end of the level 2.5 miles east of Fulton.

The general alignment of the waterway for the high and low level projects is practically the same except in Wood Creek and across the Peter Scott Swamp, where slight changes have been made to facilitate better methods of construction under the different conditions which will exist under the two plans.

In the low-level project the streams tributary to the Mohawk along the proposed route may be received into the prism of the waterway, the same as in the high-level project, but on account of the greater depth of the channel more expensive intake works must be provided.

In establishing the elevation of the summit level for this project it has been deemed expedient to make it as high as the general level of the adjacent country will permit on account of the nature of the soils through which a portion of the deep cut will have to be excavated.

The banks of the channel will be from 20 feet to 50 feet above the low-water level of the waterway for over 30 miles through the divide, and at places the clay strata are of a nature which requires back drainage to prevent landslides into the canal prism.

The land immediately surrounding the lake is largely low and swampy and will be submerged for an extent of 70 square miles with the lake raised to an elevation of 386 feet, but the saving in cost of excavation will be so much in excess of the value of the land that it will be economical and desirable to establish such maximum stage.

## EASTERN DIVISION.

The route from Herkimer to the Hudson is practically a rectification of the Mohawk River to Rotterdam Junction, then by a waterway of standard cross section for 3 miles along the south side of the Mohawk Valley, and thence across the divide through South Schenectady to the head of Normans Kill, which stream the line follows to the Hudson a short distance below the city limits of Albany.

The flood discharge of the river is approximately 45,000 cubic feet per second at Little Falls, 50,000 cubic feet at the mouth of West Canada Creek, 56,000 cubic feet at the mouth of Garoga Creek, and 80,000 cubic feet at the mouth of Schoharie Creek. With 10,000 cubic feet per second of this flow retained in the Oneida Lake Reservoir

during the extreme height of the freshet—generally not more than one day—the cross section of the channel necessary to carry the discharge with a current of less than 4 feet per second will vary from the standard section at Herkimer to one with a bottom width of 460 feet at Rotterdam for 30 feet depth at low stage.

For the 21-foot channel the cross section is standard width at Herkimer and gradually increases to 329 feet bottom width at Little Nose, from which point to Rotterdam it will cost less for a channel 30 feet deep of dimensions to carry the discharge than for a wider waterway 21 feet deep, and therefore for this reach the cross sections and estimates for the two waterways are identical.

Approximate comparative estimates have been made for 21 and 30 feet depth of waterways of standard cross section, separate from the river channel except at crossings, from which it appears that such construction would be more expensive than to rectify and deepen the river and besides would render navigation unsafe at times of high water at points where the channels would cross each other. At the commencement of the surveys it was expected that the route would follow the river to its junction with the Hudson at Troy, but from later investigations it was found that a waterway of large dimensions so located would necessarily have curves too sharp for safe navigation, would involve dangerous river crossings, and would be very expensive to construct. Preliminary surveys were made of routes from Niskayuna to Albany, Schenectady to the Hudson via Cedar Hill and via Normans Kill, but rock at suitable elevation for the foundation of structures was found only on the latter, and the other routes were therefore abandoned.

*Materials to be excavated.*—Seven diamond-drill holes were put down on the western division of the route to determine the nature of the rock to be excavated and the character of foundations on which structures will have to be built. On the eastern division no diamond-drill holes were bored, for the reason that where rock was found above bottom grade of proposed waterway its character was pretty well determined by the outcrop and from the ordinary borings.

The bed of the river at Oswego is argillaceous sandstone, and between Oswego and Fulton is mostly a mottled Medina sandstone. Between Fulton and Oneida Lake the rock, where above grade, is Clinton shale, overlaid with sand and gravel.

Through Oneida Lake the excavation will be mostly soft mud, except near Brewerton, where a small amount of rock was found.

East of Oneida Lake the rock where above grade is Utica shale, and at the divide which separates the Wood Creek and Mohawk valleys, west of Rome, there is a deposit of rock and hardpan.

East of Rome and along the Mohawk Valley to Herkimer there is a deep channel between the hills, filled in with sand, soft clay, and beds of gravel, with occasional spurs of rock projecting from adjacent hills.

At places the channel banks will require a low slope and thorough back drainage to render them secure from landslides during construction.

From about a mile below Herkimer to Little Falls quartzite rock is found from 15 feet to 35 feet below the surface, overlaid with sand and a small amount of clay, and at and below Little Falls the river flows through a solid bed of quartzite for a distance of 2 miles with a fall of about 45 feet.

Below the outcrop in the vicinity of Little Falls to Canajoharie the borings show the rock surface to be from 15 to 20 feet below the present level of bottom lands. The rock on this section above St. Johnsville is shale, and thence east is a hard limestone well adapted for use in structures.

From Canajoharie to Rotterdam but little rock is found above grade of proposed waterway, and excavation will be mostly through sand, with occasional pockets of clay and gravel.

The elevation of the water surface in the canal between Rotterdam and French Mills has been fixed at 240 feet above mean tide at New York, and the elevation of the divide between the Mohawk and Normans Kill at South Schenectady is 350 feet, through which the excavation will be mostly in shale rock.

Rock drops below grade about 1 mile south of the divide, leaving the cutting in a mixture of blue clay and gravel, with sand near the surface.

Above French Mills slate rock is found at or above bottom grade of the canal for about 2.5 miles. Shale rock is found above grade for a distance of about 2 miles near the mouth of the Normans Kill, and the excavation for the remainder of the section will be through blue clay.

Materials for construction will have to be brought in on the eastern end of the division, as none of the rock to be excavated is suitable for use in structures, but from Canajoharie westward to Oswego, good building material can be obtained within reasonable hauling distance of where needed.

*Railroad changes.*—At Oswego, where the waterway would cross the Delaware, Lackawanna and Western Railroad and the Rome, Watertown and Ogdensburg Railway, a slight change of alignment will permit both roads to use the same bridge. At Sylvan Beach, near the eastern end of Oneida Lake, the Lehigh Valley and the New York, Ontario and Western Railroad tracks will have to be raised and embankments protected with riprap, or else rebuilt on higher ground, all of which has been provided for in the estimates.

The immense traffic over the New York Central and Hudson River Railroad makes it very desirable to avoid crossing that railroad wherever possible, and for this reason the estimates provide for a new location of that road at Rome, thereby keeping the railroad south of the canal location. At the crossing of the New York Central Rail-

road below Utica it is proposed to raise the grade of the railroad sufficiently to carry it over the waterway on a viaduct.

In the Mohawk Valley there are several localities where the grades of the railroads will need to be raised in order to maintain the tracks well above the flood stages where the river is improved, and at the mouth of Normans Kill the canal as located will involve a change in the location of the Delaware and Hudson Railroad for about 1 mile.

### BRIDGES AND FERRIES.

The reports of the assistant engineers who had charge of surveys give full descriptions of localities where railroad bridges, highway bridges, and ferries will be needed, the details and estimates for which will be found in Appendixes 13 and 14.

### EXISTING CANALS.

The Erie and Oswego canals parallel the route for a considerable part of the proposed waterway, but with a proper arrangement of plans and methods of construction, the traffic on these canals need not be disturbed until the ship canal is practically completed. These canals will be of great use to the enterprise during the progress of construction in facilitating the handling of material, but before a deep waterway can be opened for transacting business the old canals will necessarily have to be abandoned.

The project, therefore, can never be undertaken by the General Government except with an understanding with the State of New York that the existing canals shall be abandoned when the work of constructing the ship canal shall have reached a stage requiring the destruction of portions of the old canal prism and structures.

### LOCKS AND DAMS.

The estimates for all structures are based on the standard designs adopted by the Board, the details of which are shown on plates 68 and 69. The locations and descriptions are given in Appendixes Nos. 13 and 14, and the locations are shown on plates 18 to 31, inclusive.

All the locks on the route except two can be built on rock foundations. The locks and dams at Amsterdam and Cranesville and the dam at Rotterdam will require artificial foundations on which to establish lock and dam structures, and as the underlying strata are mostly sand and gravel for considerable depths, the substructure work will be expensive.

### WATER SUPPLY.

An adequate supply for a ship canal of large capacity can only be obtained by constructing a down-grade feeder from Lake Erie to the summit level or by impounding the surplus water of the streams of

the central part of the State of New York in reservoirs and delivering it as needed through a feeder connecting the reservoirs with the summit level of the canal.

A preliminary examination of the difficulties to be overcome indicates that the former of these methods would be so expensive as to be practically prohibitive, and investigations were directed toward determining whether an available supply could be obtained from the watersheds of the Black and Salmon rivers.

Mr. George W. Rafter, C. E., who from large experience with previous surveys through New York State was thoroughly familiar with the natural conditions, was engaged to make a special examination of the amount of water available and to submit an estimate of the cost of the necessary reservoirs and feeders, the results of which are fully discussed in his report, Appendix No. 16.

For the high summit level project the supply necessary, including evaporation, leakage, water power, and waste, for both feeder and waterway will be about 1,600 cubic feet per second for a 30-foot waterway and 1,400 cubic feet per second for a 21-foot waterway.

To provide for this amount of supply, a reservoir has been located in the valley of the Black River having an area, when full, of 77.9 square miles, with an impounding capacity of 70,000,000,000 cubic feet, and one in the Salmon River Valley of 8.5 square miles area and storage capacity of 7,000,000,000 cubic feet.

It is expected that the volume of storage which can be secured in the Black River Valley will be sufficient to maintain an ample supply for the waterway except in long periods with small amount of precipitation, when an additional supply may be needed from the Salmon River Reservoir. The Black River storage provides also for maintaining the present low-water discharge for power purposes in the Black River below the reservoir.

A great objection to the project is the length of feeder line required and the serious delays to navigation which would result in case of stoppage of supply from breaks in the feeder or other causes. The Salmon River Reservoir, the feeder from which is not liable to accidents, is therefore regarded as essential to insure a safe and continuous supply at all times.

The feeder from the north end of the reservoir at Carthage to the junction with the waterway west of Rome is 94.4 miles long, nearly one-half of which is the natural bed of streams and ponds.

A study has been made of an alternate tunnel project as a substitute for the feeder line, which seems to have sufficient merit to warrant further investigation as to feasibility if the proposition to build a ship canal via the Mohawk route should be favorably considered.

This tunnel would leave the south end of the Black River reservoir at Lyons Falls and open into the Upper Mohawk at the village of North Western, a distance of 20.5 miles from the reservoir, and thence dis-

charge through the channel of the Mohawk into the waterway near Rome.

The costs of the two systems, as estimated, are approximately the same, and, unless investigations by means of diamond-drill borings should develop insuperable difficulties, the tunnel line will be the preferable plan, as the amount of waste and cost of maintenance would be much less than for the open feeder, and the danger of accidents would be inappreciable.

For the low-level plan, with Oneida Lake for a reservoir on the summit level, ranging from 379 to 386 feet above mean tide, the storage capacity would be about 25,000,000,000 cubic feet, a surplus of nearly 3,000,000,000 above the amount which would probably be needed in average years of precipitation and evaporation on the watershed. To provide against any deficiency arising from a series of years of small precipitation, the Salmon River reservoir has been included in the low-level project, so that the deficiency during dry years may be easily supplied, and, if it is deemed advisable, the range of stage of the summit level may be decreased.

The volume of water which may at times be needed from the Salmon River reservoir is such that it may be brought down the channel of Fish Creek without any considerable improvement. The flood discharge of the creek is at times over 4,000 cubic feet per second, while the amount which will be required to pass through it from Salmon River will not exceed 350 feet per second.

*Estimate for 20-foot channel.*

| | |
|---|---|
| **High-level project:** | |
| Excavation | $80,049,352 |
| Retaining walls, slope walls, and back fill | 11,057,538 |
| Entrance of streams | 44,116 |
| Right of way | 8,776,027 |
| Embankment | 436,855 |
| Bridges and ferries | 4,672,194 |
| Railway and highway changes | 1,082,523 |
| Cribs at lock entrances | 6,278,431 |
| Locks | 39,958,498 |
| Operating plant | 2,800,000 |
| Dams | 3,637,115 |
| Water supply | 18,080,752 |
| Breakwater at Oswego | 1,190,317 |
| | 178,063,714 |
| Engineering, superintendence, and contingencies, 10 per cent | 17,806,371 |
| Total | 195,870,085 |
| **Low-level project:** | |
| Excavation | $98,378,038 |
| Retaining walls, slope walls, and back fill | 13,927,042 |
| Entrance of streams | 44,116 |
| Right of way | 11,284,392 |
| Embankment | 157,015 |

*Estimates for 30-foot channel*—Continued.

| | |
|---|---|
| **Low-level project—Continued.** | |
| Bridges and ferries | $4,734,574 |
| Railway and highway changes | 1,196,630 |
| Dams | 3,122,610 |
| Cribs at lock entrances | 5,438,677 |
| Locks | 37,614,895 |
| Operating plant | 2,600,000 |
| Water supply | 2,062,295 |
| Breakwater at Oswego | 1,190,317 |
| | 181,750,601 |
| Engineering, superintendence, and contingencies, 10 per cent | 18,175,060 |
| Total | 199,925,661 |

*Estimate for 21-foot channel.*

| | |
|---|---|
| **High-level project:** | |
| Excavation | $58,587,936 |
| Retaining walls, slope walls, and back fill | 7,335,266 |
| Entrance of streams | 44,116 |
| Right of way | 8,785,027 |
| Embankment | 434,854 |
| Bridges and ferries | 4,191,365 |
| Railway and highway changes | 1,082,523 |
| Dams | 3,637,111 |
| Cribs at lock entrances | 6,226,103 |
| Locks | 25,495,352 |
| Operating plant | 2,800,000 |
| Water supply | 18,080,752 |
| Breakwater at Oswego | 721,380 |
| | 137,422,785 |
| Engineering, superintendence, and contingencies, 10 per cent | 13,742,279 |
| Total | 151,165,064 |
| **Low-level project:** | |
| Excavation | $74,580,722 |
| Retaining walls, slope walls, and back fill | 9,540,963 |
| Entrance of streams | 44,116 |
| Right of way | 11,293,392 |
| Embankment | 155,014 |
| Bridges and ferries | 4,262,607 |
| Railway and highway changes | 1,196,630 |
| Dams | 3,122,610 |
| Cribs at lock entrances | 5,334,394 |
| Locks | 24,054,221 |
| Operating plant | 2,600,000 |
| Water supply | 2,062,295 |
| Breakwater at Oswego | 721,380 |
| | 138,948,344 |
| Engineering, superintendence, and contingencies, 10 per cent | 13,894,834 |
| Total | 152,843,178 |

## ST. LAWRENCE-CHAMPLAIN ROUTE.

This route extends from the foot of Lake Ontario to the lower end of the Oswego-Mohawk route at the mouth of the Normans Kill, below Albany, a distance of 264 miles, and was investigated in three divisions: First, St. Lawrence division, from the foot of Lake Ontario to the lower end of Lake St. Francis, on the St. Lawrence River; second, the northern division of the Champlain route, consisting of a canal from Lake St. Francis to Lake Champlain, and, third, the Hudson River division, from deep water in Lake Champlain to the junction with the Oswego-Mohawk route below Albany.

### PHYSICAL CHARACTERISTICS OF THE ROUTE.

From Lake Ontario to the lower end of Lake St. Francis, where the route leaves the St. Lawrence River, any system of improvement must consist of river rectification and of locks and dams for slack-water navigation around the rapids.

Above Ogdensburg the channels are so deep that the slope is very small, but from Ogdensburg to Valleyfield the average fall of the river is about 1.2 feet per mile, a large portion of which is concentrated at the rapids of the river.

East of the lower end of Lake St. Francis the country for over 20 miles is from 10 to 12 feet lower than the lake, through which valley the St. Louis, Chateauguay, and English rivers flow. East of this valley a ridge of limestone and quartzite forms the drainage divide between these streams and Lake Champlain.

The valley of Wood Creek from near Smiths Basin to Lake Champlain and of Bond Creek south from the divide to the Hudson River below Fort Edward constitute a narrow trough between the foothills of the Adirondack and Green Mountains, through which any waterway from Lake Champlain to the Hudson will have to be located.

The Hudson River between Fort Edward and Troy consists of a series of pools separated by water-power dams at the rapids over the rock reefs between the different pools.

From the State dam at Troy to New York the river is a tidal stream.

### ST. LAWRENCE DIVISION.

The surveys and investigations of this division were made, under the supervision of the Board, by Mr. J. W. Beardsley, Assistant Engineer, who organized a party for doing the work in August, 1898, and completed the field work in June, 1899.

The St. Lawrence River from Tibbetts Point to the foot of Lake St. Francis, a distance of 142 miles, has a fall of 93 feet, distributed in rapids and river slopes under conditions which make any project for the improvement of the river for deep-draft vessels difficult and expensive.

The depth of the Canadian system of canals between Lake Ontario

and deep water in the St. Lawrence River below Montreal is such that any variation in the volume of flow of the river is of great importance to navigation interests, and therefore any project which is to have the approval of the Canadian government must be such that the low-water discharge of the river can be maintained fully as large as under natural conditions.

The river above Galops Island is generally wide and deep, and for a distance of 65 miles the total fall at standard low water is only 1 foot. The navigable channel through the Thousand Islands and Brocks Group, as shown on the charts, is from 40 feet to 120 feet deep, but in places is less than 500 feet wide, and in case the river should be improved for 30-foot navigation it is possible that points of rock above grade may be found within the limits of the channel which have not been located by previous surveys.

No estimate has been included for this section of the river, as the United States Lake Survey charts, which are considered reliable, indicate a channel of over 30 feet depth, with a minimum width of about 500 feet.

At the Galops Rapids the river has a fall at low water of about 10 feet in a distance of 3 miles, with two channels having a combined cross section of about 40,000 square feet. It is proposed to improve this reach of the river by closing the channels between Galops Island, Benedict Island, Raycroft Island, Lalone Island, Sheldons Island, and the mainland, and enlarging the discharge section of the channel north of Galops Island so as to maintain the normal discharge of the river, with the south channel improved for slack-water navigation.

The head of the North Channel is partly obstructed by Adams Island, below which there are heavy rapids, so that by enlarging the channel between Galops and Adams Island for a distance of about 2,000 feet any increase of discharge necessary to compensate for loss from slack-water navigation in the South Channel may be obtained; and, in fact, if desirable, regulating works can be established by which the volume of discharge of the river can be controlled at all times.

The project on which estimates are based consists in closing the outlets of the South Channel, so as to secure slack-water navigation and to lock down into the pool below with a lock at Sheldons Island, and also to enlarge the head of the North Channel sufficiently to maintain the normal flow of the river when the South Channel is closed.

From the foot of Sheldons Island to the head of Ogdens Island, a distance of about 8 miles, the river consists of three pools, separated at Long Point and Rockway Point by narrow, deep channels, having maximum current velocities of about 10 feet per second and mean velocities of 6 feet per second on curves of 2,000 feet radius.

The curvature is so sharp that the water surface of the eddy below Long Point is 2.25 feet lower than that of the pool 4,000 feet above,

and at Rockway Point 3.7 feet lower at the eddy than 7,000 feet above on the upper side of the point.

The river is susceptible of improvement at these points by two different methods, viz: first, by cutting canals across the points and locking down into the pools below, and, second, by enlarging and straightening the prism of the river opposite the points, so as to diminish the velocity of current and increase the radius of the channel curve sufficiently to make the reach safely navigable for all classes of vessels.

An investigation of the natural conditions developed the fact that the latter method could be carried out at less cost than improvement by locks and canals, and, as the time required for the passage of vessels with enlarged river would be less than with locks, the plans and estimates have been based on the project for rectifying the river channel.

The natural low-water fall of the river from the foot of Sheldons Island to the head of Ogdens Island is about 9.6 feet which, with the river channel enlarged and straightened at Long and Rockway points, will be reduced to 7.3 feet and the slope made nearly uniform over the entire reach.

An interesting feature of the proposed improvement is that the slope of the upper pool will be decreased and of the two lower pools increased by the change which will be made in the velocity of the currents flowing into and out of the respective pools.

From deep water in the pool above Ogdens Island to slack water below Rapide Plat, a distance of about 3½ miles, it is proposed to construct a navigable channel by cutting a short canal through Leishmans Point into Little River on the south side of Ogdens Island and constructing a lock and dam at Clarks Point, thereby making slack-water navigation around the rapids.

There is at present a water-power dam across Little River from Waddington to Ogdens Island, about 1 mile above the proposed location for lock and dam, which would be destroyed by the proposed improvement, but much better facilities for developing power may be had at the proposed site.

The lift required at the Clarks Point lock will be about 11.8 feet for standard low water.

From Clarks Point to Bradfords Hill, a distance of 7 miles, the natural channel will have to be widened in several places to obtain a 21-foot channel 600 feet wide, and for 30-foot navigation the river will have to be widened and deepened for a large part of the reach.

From Bradford Hill to Richards Point, at the head of the Long Sault Rapids, there is a good navigable channel of over 21 feet depth, but for 30-foot navigation a cut about 1,700 feet long will be required through the shoal about a mile above Louisville landing.

From Richards Point through the Long Sault Rapids to the mouth of Grass River at the head of Cornwall Island (10.6 miles) there is a

fall of about 48 feet which it is proposed to overcome by constructing a canal of standard cross section through the flat country to the south of the St. Lawrence River with a lock of 48 feet lift near the lower end.

The surveys and investigations were made with reference to establishing two locks of 24 feet lift each, but rock could not be found at the proper elevation for such a project, and therefore designs and estimates have been made for a single lock. The cost for a single lock will be somewhat less than for two, and the time for passing a vessel will average over a half hour less for a single lift than with two locks having half the total lift each.

Below the Long Sault Rapids the channel will require widening in places to obtain 21 feet depth, 600 feet wide, and for 30-foot navigation the channel will have to be deepened and widened for the reaches shown on plates 42 and 43, and described in detail in the report of the assistant engineer in charge of the surveys, Appendix No. 11.

The fluctuation of the water surface above and below the Long Sault Rapids varies from 2 to 4 feet under normal conditions of the river, but at times of ice jams in the vicinity of St. Regis Island, which last from one to three months, the water at the mouth of Grass River generally rises from 10 to 25 feet above low stage.

MATERIALS TO BE EXCAVATED.

Borings were made at frequent intervals in the bed of the river and along the alignment of the canal sections to determine the nature of the material above bottom grade of the proposed waterway.

Rock, where above bottom grade of the waterway, is a dark gray limestone, and well adapted for use in constructing dams, locks, slope, and retaining walls. The higher portions of the points and islands crossed by the proposed route have a rich, shallow, loamy surface overlying a core of bowlder, clay approaching close to the surface on the upstream side, while on the downstream side considerable clay, sand, and softer materials are frequently found, a complete classification of which will be found in Appendix No. 11.

*Estimates for 30-foot channel.*

| | |
|---|---|
| Excavation | $26,460,021 |
| Retaining walls, slope walls, and back fill | 567,716 |
| Embankment | 88,039 |
| Right of way and drainage | 270,775 |
| Highways | 920 |
| Bridges and ferries | 242,888 |
| Locks | 3,348,313 |
| Dams | 129,011 |
| Operating plant | 300,000 |
| Piers and cribs | 878,170 |
| | 32,285,853 |
| Engineering, superintendence, and contingencies, 10 per cent | 3,228,585 |
| Total | 35,514,438 |

*Estimates for 21-foot channel.*

| | |
|---|---|
| Excavation | $14,620,422 |
| Retaining walls, slope walls, and back fill | 506,557 |
| Embankment | 86,163 |
| Right of way | 270,775 |
| Highways | 920 |
| Bridges and ferries | 242,888 |
| Locks | 2,198,689 |
| Dams | 129,011 |
| Operating plant | 300,000 |
| Piers and cribs | 760,132 |
| | 19,115,557 |
| Engineering, superintendence, and contingencies, 10 per cent | 1,911,556 |
| Total | 21,027,113 |

NORTHERN DIVISION.

The surveys and investigations of routes from the St. Lawrence River to Lake Champlain were commenced in July, 1898, by a party under the charge of Mr. Frank P. Davis, assistant engineer, and were completed in May, 1899, the details of which will be found in Appendix No. 12.

A careful barometric reconnoissance was made by the Board in advance of field work and limits fixed for the location of routes and areas of country to be covered by the surveys. The divide between Lake Champlain and the St. Lawrence is about 12 miles west of Kings Bay and has an elevation of 218 feet above mean tide at New York, or about 66 feet above the low-water stage of Lake St. Francis.

The surface of the country northwest of the divide gradually drops, and for 23 miles at the western end of the division is below the level of Lake St. Francis; but to avoid deepening the cut through the divide the Lake St. Francis level is carried through to within 4 miles of Lake Champlain.

The proposed route was located with reference to keeping on land of such elevation that the material to be excavated would be generally sufficient to form the embankments, and also that the surface of the canal should not be so much above the general level of the country as to be dangerous to adjacent lands.

For a distance of about 12 miles west of Aubrey the surface of the canal will be from 10 to 12 feet above the general level of the adjacent country, and for a waterway of 21 feet depth more material will be required for embankments than can be obtained from the excavation, and for 10 miles the estimates have been made for depths of 23 to 25 feet.

In the preliminary project it was proposed to cross the Chateauguay River with an aqueduct a short distance below the dam at Ormstown, but owing to danger of floods from ice jams a new location and estimates for the waterway were made in October, 1899, based on plans

for raising the level of the Chateaugay to that of the canal, by building a dam about 3,200 feet above the site of the proposed aqueduct, and confining the river between dikes on each side of the river from Ormstown to Huntington, about 9½ miles.

A similar plan was adopted at the crossing of the English River near Aubrey, with overflow weirs for the discharge of flood waters from the river. In both cases the drainage of adjacent lands has been provided for by ditches and by siphons under the canal.

The Chazy River, which flows into Lake Champlain at Kings Bay, is intersected by the waterway location near Champlain, and as the stream is the source of water supply for the town and for power purposes, it has been necessary to make designs and estimates for rectifying the river channel so as to take the river discharge into the waterway without injury to the existing water rights, the details of which are fully described in Appendix No. 12.

LOCKS.

In order to maintain a water supply for the Hudson River division of the Champlain route it is proposed to regulate the level of Lake Champlain at or above a stage of 100 feet above mean tide at New York, making the fall from Lake St. Francis to Kings Bay about 52.4 feet. This can be overcome by a single lock for the total lift, or by two locks of 26.2 feet lift each; but since the time for a passage of a vessel will be about a half hour less with a single lock than with two, and as the cost of construction and maintenance will be less, designs of structures and estimates have been made for a project with single lock.

The extreme fluctuation of Lake St. Francis during the season of navigation is about 3.5 feet, and to prevent the excessive currents and high water in the level of the canal a guard lock is required near the entrance. This, however, will have to be operated as a lock for only a short period of each year.

WATER SUPPLY.

The supply of water for lockage on the Hudson River Division and to furnish the necessary flow down the Richelieu River during low-water seasons will require about 1,500 cubic feet per second for from one to three months each year, or a mean flow of one-fourth of a foot per second in a waterway 30 feet deep and one-third of a foot per second in a 21-foot waterway.

MATERIAL TO BE EXCAVATED.

Borings were made at intervals of about 1,000 feet along the alignment of the route to determine the elevation of the rock surface where above bottom grade of the canal, and four diamond-drill holes were put down at locations which show the general character of rock to be excavated and the nature of the foundations for locks and for the Chateauguy River Dam. (See Appendix No. 18.)

From the St. Lawrence to the Chateauguay at Ormstown the bed of the canal will be in limestone rock for about one-half the distance. From Ormstown to the English River the cutting will be mostly through clay, with occasional mounds of bowlders, and from the English River to Champlain the cutting is through limestone, sandstone, and quartzite rock. The soil overlying the rock is mostly a stiff clay with occasional bowlders.

Rock for concrete, slope, and retaining walls can be obtained within reasonable hauling distance from material to be excavated, but all sand for construction will probably have to be brought from either Lake St. Francis or Lake Champlain.

*Estimate for 30-foot channel.*

| | |
|---|---|
| Excavation | $47,792,597 |
| Retaining walls, slope walls, and back fill | 2,630,108 |
| Embankment | 1,705,922 |
| Right of way | 681,590 |
| Railway changes | 218,599 |
| Bridges and ferries | 1,117,949 |
| Entrance of streams | 31,645 |
| Dams, drains, sluice gates, etc | 243,240 |
| Cribs at lock approaches | 151,436 |
| Locks | 2,526,653 |
| Operating plant | 200,000 |
| Regulating works, Lake Champlain | 890,244 |
| | 58,189,983 |
| Engineering, superintendence, and contingencies, 10 per cent | 5,818,998 |
| Total | 64,008,981 |

*Estimate for 21-foot channel.*

| | |
|---|---|
| Excavation | $34,978,172 |
| Retaining walls, slope walls, and back fill | 1,804,186 |
| Embankment | 1,766,991 |
| Right of way | 681,590 |
| Railway changes | 218,599 |
| Bridges and ferries | 1,020,247 |
| Entrance of streams | 31,645 |
| Dams, drains, sluices, gates, etc | 243,240 |
| Cribs at lock approaches | 115,234 |
| Locks | 1,606,832 |
| Operating plant | 200,000 |
| Regulating works, Lake Champlain | 890,244 |
| | 43,556,980 |
| Engineering, superintendence, and contingencies, 10 per cent | 4,355,698 |
| Total | 47,912,678 |

## REGULATING LAKE CHAMPLAIN.

The project of a down-grade canal from Lake Ontario to Albany, via Lake Champlain and Hudson River, requires that the supply of water for locks south of Lake Champlain be taken from the lake, and in

order to secure an adequate flow from Whitehall to Fort Edward the level of the lake must be maintained at an elevation of about 100 feet above mean tide at New York. The fluctuation of the monthly mean levels of the lake is about 6.5 feet, which must be reduced to 1.5 feet in order to properly control the flow from the lake to the Hudson River.

The outflow from the lake through the Richelieu River varies from 4,000 cubic feet per second at low water to about 36,000 cubic feet per second at high water, which is utilized at Chambly, Quebec, for developing power, and must be maintained fully as large for low stages as under natural conditions.

To accomplish this it is proposed to construct a dam across the foot of the lake 1.5 miles south of Rouses Point, with a lock for the passage of vessels, and sluice gates of such dimensions that, when all the gates are open, the maximum volume of supply to the lake may be passed. The details of this project are described in Appendix No. 8.

ESTIMATE.

| | |
|---|---|
| Lock and channel | $353,364 |
| Regular sluices | 134,258 |
| Dam | 402,622 |
| | 890,244 |
| Engineering, superintendence, and contingencies, 10 per cent | 89,024 |
| Total | 979,268 |

HUDSON RIVER DIVISION.

The surveys and examinations of this division were made by a party under the direction of Mr. C. L. Harrison, assistant engineer, between April, 1898, and January, 1899, and are fully discussed in Appendix No. 10.

The division extends from deep water in Lake Champlain at Port Henry to the junction with the Oswego-Mohawk route at the mouth of Normans Kill, below Albany, a distance of 109 miles, made up as follows: Narrows of Lake Champlain, 36 miles; canal from Whitehall to Fort Edward, 23.4 miles; canalized river Fort Edward to mouth of Normans Kill, 49.6 miles.

From the State dam at Troy to the mouth of Normans Kill the waterway is part of the tidal or Lower Hudson, but has been included in this division for the purpose of comparison of routes.

The low-water elevation of the Hudson River at Fort Edward under present conditions is 117.6 feet above mean tide at New York, and is maintained at this stage by a dam at Fort Miller, 7.1 miles below.

Two different projects for a waterway from Lake Champlain to the Hudson were investigated, viz: first, a high-level canal with summit elevations at 117.6 feet above mean tide, and water supply for operation and lockage to be obtained from reservoirs on the Upper Hudson;

and, second, a down-grade canal with a summit elevation of 100 feet from Lake Champlain to Northumberland, 2.5 miles below Fort Miller, with water supply to be obtained from Lake Champlain when the Hudson River flow is not in excess of that needed for power purposes.

A preliminary estimate developed the fact that the cost for additional locks, reservoirs, and damages to water-power privileges would make the cost of the high-level canal nearly the same as for the down-grade waterway, and as the latter would cost less to maintain and would save about one hour in time of passage of each vessel, it was adopted as the project on which to base estimates.

The waterway from Lake Champlain to Fort Edward will be in excavation for the entire distance, and has been designed and estimated for the standard dimensions of cross section shown on figs. 2 and 3, but from Fort Edward to Albany the cross section must be such as to not only afford good navigation, but to carry the flood waters of the river with a velocity which will not erode the banks, or less than 4 feet per second.

From a careful study of the records of previous surveys, and from the elevations of well established high-water marks, it is safe to state that the range of the floods for the past sixty years is quite accurately known.

During this period two notable high waters have occurred—April, 1869, and April, 1896, the former being from 1.5 to 3 feet higher than the latter, as shown by the records for different points. A flood like that of 1896 is not likely to occur oftener than once in fifteen to twenty years, and, since the duration of the maximum flood seldom exceeds one day, a channel designed to carry the discharge with a mean velocity of less than 4 feet per second may be considered safe. From the depths on the dams at Fort Edward and Mechanicville, and from the recent observations at Cornell University to determine the coefficient of the weir formula, it has been found that the discharge at the two dams in 1896 was, respectively, 47,700 cubic feet per second and 65,800 cubic feet per second.

In fixing the cross sections for the waterway it was assumed that 17,000 cubic feet per second could be turned toward Lake Champlain through the canal at times of heavy floods in the Hudson, thereby reducing the volume of maximum flow between Fort Edward and Fort Miller to 32,000 cubic feet per second; 35,000 cubic feet per second at Dam No. 2, and 48,800 cubic feet per second at Dams Nos. 3, 4, and 5.

At low water the pools between respective locks are practically level, which fixes the elevation of the bottom of the waterway, but, since the depth on the crests of the dams is about 5 feet more at times of freshets, a system of movable crests for these dams can be constructed, by which the low-water level may be raised from 3 to 4 feet, thereby

diminishing the range of stage a like amount, and at the same time largely reducing the amount of excavation.

The low-water stage under present conditions is not definitely fixed, for the reason that the water wheels installed at the dams have a greater capacity than the volume of low-water flow, and as a result the water in the pools is often drawn down from 1 to 2 feet below the crests of the dams. To maintain the required navigable depth with the river improved by locks and dams, the use of water would have to be limited to the volume of supply.

If the location and elevation of dams can be maintained nearly the same as at present, it is evident that the industries depending upon the power at the dam sites will not be materially modified, and if movable crests for the dams be used the amount of available power at low water will be considerably increased.

Fortunately such plan can be followed, except at Fort Miller, where it will be necessary to completely remove the dam in order to carry the Champlain level to Northumberland.

Starting with a low-water elevation of 100 feet above mean tide in the summit level, it is proposed to make the drop from Lake Champlain to tide water with six locks, with lifts varying from 15 to 20 feet each.

### MATERIAL TO BE EXCAVATED.

In Lake Champlain there is a small quantity of shale above bottom grade of the 30-foot channel, and at the elbow about 1 mile north of Whitehall both channels cut for a distance of 800 feet a projecting point of quartzite rock about 35 feet above lake level.

The earth in the bed of the lake is mostly sand, silt, and mud. From Whitehall to Fort Ann the rock, where above grade, is a hard quartzite overlaid with sand and clay.

Between Fort Ann and Fort Edward a hard shale or slate is found above grade in several places, which disintegrates rapidly when excavated and exposed to the air.

The cutting through the summit of the divide between Lake Champlain and the Hudson is from 30 to 45 feet above the surface of the proposed waterway for a distance of 10 miles.

From Fort Edward to Normans Kill the rock, where cut by the channel, is a slate or shale in irregular layers, with a sharp dip to the eastward, overlaid with sand and clay.

In the Hudson below the State dam at Troy there are a number of large deposits of bowlders, stone, and gravel, mixed with clay and sand.

On the northern portion of the division sand and rock suitable for concrete and for slope and retaining walls can be obtained from the excavation, but for all structures on the Hudson material will have to be brought in.

STRUCTURES.

One guard lock and six locks and dams will be required, at four of which movable crests on the dams will be needed to secure the best results at minimum cost.

The location and description of bridges needed are given in Appendix No. 10.

Power for operating gates and machinery may be generated at each lock, and, as the water supply is to be brought from the St. Lawrence River, such arrangement will not infringe on existing water rights.

STABILITY OF CHANNEL.

The Upper Hudson carries but little sediment, except at times of heavy floods, and a comparison of the present profile with that from a survey made in 1866 indicates that there has been only slight changes in the bed of the river and alignment of the banks, and, since the slope and velocity of current in the proposed waterway will be less than under present conditions, it is probable that but little excavation will be needed to mantain a navigable channel.

*Estimate for 30-foot channel.*

| | |
|---|---|
| With fixed dams: | |
| Excavation | $82,258,924 |
| Retaining walls, slope walls, and back fill | 2,455,367 |
| Right of way | 3,414,350 |
| Entrance of streams | 173,196 |
| Bridges and ferries | 2,062,355 |
| Gates for by-pass | 52,115 |
| Locks | 6,879,095 |
| Dams | 139,568 |
| Operating plant | 700,000 |
| Piers at lock approaches | 764,145 |
| Railroad changes | 124,500 |
| | 99,023,615 |
| Engineering, superintendence, and contingences, 10 per cent | 9,902,361 |
| Total | 108,925,976 |
| With movable dams: | |
| Aggregate cost of above items | 93,833,615 |
| Engineering, superintendence, and contingencies, 10 per cent | 9,383,362 |
| Total | 103,216,977 |

*Estimate for 21-foot channel.*

| | |
|---|---|
| With fixed dams: | |
| Excavation | $53,024,282 |
| Retaining walls, slope walls, and back fill | 1,951,893 |
| Right of way | 3,414,350 |
| Entrance of streams | 173,196 |
| Bridges and ferries | 1,903,943 |
| Gates for by-pass | 43,385 |

*Estimate for 21-foot channel*—Continued.

| | |
|---|---|
| With fixed dams—Continued. | |
| Locks | $4,297,015 |
| Dams | 139,568 |
| Operating plant | 700,000 |
| Piers at lock approaches | 714,341 |
| Railroad changes | 124,500 |
| | 66,486,473 |
| Engineering, superintendence, and contingencies, 10 per cent | 6,648,647 |
| Total | 73,135,120 |
| With movable dams: | |
| Aggregate cost of above items | 61,752,473 |
| Engineering, superintendence, and contingencies, 10 per cent | 6,175,247 |
| Total | 67,927,720 |

THE TIDAL HUDSON.

With the exception of a short reach of river opposite Germantown, there is a navigable channel 21 feet deep from Hudson City to tide water at New York, but for 30-foot navigation dredging will be required near Livingston Light, at Germantown Crossing, at Barrytown Crossing, opposite Rhinebeck, in Haverstraw Bay, and in Tappan Sea.

From Hudson to the State Dam at Troy navigation is obstructed by numerous bars which, under the existing project for improvement of the river, are being removed to a depth of 12 feet for a width of 400 feet.

Below Albany the river is susceptible of easy improvement for a depth of 30 feet, but will probably be expensive to maintain for depths of over 21 feet. Between Troy and Albany a large amount of rock is encountered above the bottom grade of both the 21-foot and 30-foot channels, and for a distance of 6,000 feet below the State Dam the material overlying the bed rock is largely stone and bowlders and will be expensive to excavate. The adoption of Normans Kill as a part of the Oswego-Mohawk route eliminates the worst features of the Hudson River improvement from the proposed route and leaves that part of the project easy to construct.

The tidal division of the river extends to the State Dam at Troy, but owing to the bars above Albany the range of the tides diminishes rapidly above that place.

At an average stage of the river the ebb currents are well defined, but the effect of flood tide is only apparent from slackening of the current and the rising of the water surface. At the low stage of the river the tidal currents become alternating and are well defined in both directions.

A study of the rise and fall of the tides under the present conditions of the river channel indicates that, with the channel deepened to 21 feet, the elevation for low water at the State Dam would be about 1.23 feet above mean low-water at New York, and that the range of the tides would be largely increased.

The proposed project for the improvement of the river is based on channels 21 and 30 feet deep, 300 feet wide for a distance of 29,800 feet below the State Dam, 400 feet wide for 36,640 feet, and 600 feet wide thence to New York. The existing regulating dikes can be utilized in case the improvement should be carried out, but about 23,500 linear feet of dikes additional will be needed to prevent inflow of silt from cross currents due to rise and fall of tides and to limit the width of the channel at points where the cross section of the river is large in relation to the depth.

The reach from the State Dam to the mouth of Normans Kill, which constitutes a part of the Champlain route, will be the most difficult to improve and maintain.

From the junction of the two routes to deep water in the lower river the material to be excavated is mostly sand, gravel, and clay, except at a few places where shale rock is found above the bottom grade of the proposed waterways.

There are five bridges across the river in the vicinity of Albany and Troy which will have to be reconstructed in case the waterway via the Champlain route should be adopted, but below the junctions of the two routes at the mouth of the Normans Kill the only bridge across the river is that at Poughkeepsie, which has a clear height above the water surface of 160 feet.

The general location and width of proposed channels are shown on plates 56–59 and are described in Appendix 15.

*Estimate.*

BELOW NORMANS KILL.

| | |
|---|---|
| 30-foot channel: | |
| Excavation | $9,233,103 |
| Dikes | 206,413 |
| | 9,439,516 |
| Engineering, superintendence, and contingencies, 10 per cent | 943,952 |
| Total | 10,383,468 |
| 21-foot channel: | |
| Excavation | 3,575,318 |
| Dikes | 206,413 |
| | 3,781,731 |
| Engineering, superintendence, and contingencies, 10 per cent | 378,173 |
| Total | 4,159,904 |

## INTERMEDIATE CHANNELS OF THE LAKES.

Under existing conditions of the harbors and waterways on the Great Lakes a ship canal of 21 or more feet in depth from the seaboard would terminate in Lake Erie without a single lake harbor of sufficient depth to admit ships of the draft which could navigate the canal, and without a connecting waterway with the upper lakes of sufficient dimensions to allow the passage of fully loaded vessels from the ship canal.

The shallow depths over the obstructions to navigation in the St. Marys, St. Clair, and Detroit rivers fix the limit of draft of vessels for the entire lake system of waterways, the improvement of which is of the highest importance to the internal commerce of the country. The act of Congress of July 13, 1892, provided for the construction of a ship channel having a navigable depth of 20 feet through the shallows of the connecting waters of the Great Lakes where such depths had not already been obtained by previous improvements.

The channels actually constructed under this act are reported to be 20 feet deep below the mean stage of Lake Superior and St. Marys River, about 20.5 feet deep below the mean stage of Lake Huron, St. Clair, and Detroit rivers, and 21 feet deep below mean level of Lake Erie, except through a portion of the lower reach of the Detroit River, where the least depth at low water is about 18 feet, making an improvement of about 3 feet at this locality necessary to obtain a navigable channel of 21 feet depth through the river at low stage.

The system of improvement of lake waterways in vogue consists in deepening existing channels at places where of less depth than required for ships best adapted for transporting the commerce of the lakes, the result of which has been that the general level of the whole system has been lowered.

The mean level of Lake Huron is apparently about 1 foot lower than it was fifteen years ago, which change has resulted from the enlarging and deepening of channels for waterway improvements and from the natural erosion of the bed of the river at the outlet of the lake. This change of stage in Lakes Huron and Michigan has produced a like effect in the depth of channel through the St. Marys River below the St. Marys Rapids. Lakes Erie, Huron, and Michigan have a fluctuation from high to low stages of about 4.5 feet, and since the depth through the shallow portions of the connecting waterways is less than that required for ships of dimensions best adapted for the lake traffic, vessels are generally constructed for a draft equal to the average depth to be expected in the channels.

The only apparent remedy for this condition is to make the connecting channels equal in depth to those of the terminal harbors, or to regulate the level of the lake so as to maintain the depth in shallow channels nearly constant during the season of navigation.

Estimates have been made for channels 21 and 30 feet deep, when Lake Erie is at stage of standard low water, and also for the stage which would exist if the level be maintained at fixed elevation by regulation.

### LAKE ERIE CHANNELS.

At the head of Lake Erie the depth at low stage of the lake is less than 20 feet for a distance of about 5 miles from the mouth of the Detroit River, but with the level which would exist with the lake regulated no improvement would be required for a 21-foot channel.

To establish 30-foot navigation a cutting would have to be made in the bed of the lake for about 10 miles, having a depth of about 10 feet for over half the distance. Such a channel would deteriorate rapidly from deposits due to wave action and cross currents, and would require dredging annually to maintain.

### DETROIT RIVER CHANNELS.

For a distance of about 5 miles near the mouth of the river a crooked channel, 18 feet to 20 feet deep at mean stage, has been excavated through the bowlder and limestone reefs which obstruct the waterway, but for safe navigation the channel should be straightened and made the required depth for a width of at least 600 feet.

### LAKE ST. CLAIR.

The depth of the lake along the channel line is about 19 feet for low stage under normal conditions, and 21 feet at the low stage which would exist with the level of Lake Erie regulated. The grade of a 21-foot navigable channel would, therefore, be but little below the natural bed of the lake, but for 30-foot navigation the cutting would be from 9 feet to 11 feet deep, and no doubt would require frequent dredging to maintain a navigable depth for full width of the waterway.

### ST. CLAIR FLATS.

A channel 300 feet wide and 20 feet deep at mean stage has been dredged between piers from deep water in the South Channel to the lake. The velocity of current through the canal is about 1.7 miles per hour, and to make navigation safe for the great volume of commerce through the waterway the channel should be widened to 600 feet and deepened to correspond with whatever depths may be adopted for the lake waterways.

The excavation would be mostly sand, clay, and gravel and can be easily executed with a hydraulic dredge.

Through the St. Clair River but little improvement will be needed above the delta for either the 21 or 30 foot waterways, except to widen and straighten the channel at some of the bends and to cut through the middle grounds at Port Huron, Marysville, and St. Clair.

### LAKES HURON AND MICHIGAN.

At the outlet of Lake Huron a channel 21 feet deep and over 600 feet wide extends from deep water in the lake into the head of the St. Clair River. Through the eastern end of the bar between the lake and the head of the river a channel 300 feet wide and 40 feet to 70 feet deep has been scoured during recent years, and probably will continue to widen from natural erosion. The material eroded from the bar is very likely deposited on the middle grounds which have formed in the river opposite Port Huron and Marysville. A navigable 30-foot channel through this waterway will require that the channel which has been scoured through the natural barrier at the outlet of the lake be dredged to a width of 600 feet. The decrease of slope which would be required for the discharge through such enlarged outlet would lower the general level of Lakes Huron and Michigan, and unless the low-water slopes of the river be decreased by regulating the levels of Lakes Erie and St. Clair the results might be a serious objection to such a project of improvement.

### ST. MARYS RIVER.

The route from the locks at the Sault to deep water in Mud Lake has been located through Hay Lake and the West Neebish Channel for the reason that the distance is less and the route can be constructed for less cost than through the other branches of the river.

The estimates are based upon channels 21 and 30 feet deep, 600 feet wide for standard low water in Lake Huron, and also for the low stage with the level of Lake Erie regulated.

At the St. Marys Falls the three existing locks are considered ample to accommodate the traffic of Lake Superior ports as long as the depth of the lake harbors does not exceed 21 feet, but for greater depth of harbors and connecting waterways a new lock will be required. It is true that one of the larger locks is on the Canadian side of the river, but since the vessels of each country have equal privileges in all of the locks the facilities are ample for the commerce of the lakes. In case of any controversy between the two countries, it is probable that the traffic would be light and the existing American locks would easily accommodate the business.

Above the locks channels 600 feet wide have been estimated from the canal to deep water at the head of the river.

Above the head of the St. Marys River there are no obstructions to 30-foot navigation on the route, outside of the harbor entrances.

The depth to which the entrances of the lake harbors can be improved and economically maintained is really the limit of depth which should be fixed for the shallows of the connecting waterways. Until this limit is reached there will be a demand for deeper waterways, and any greater depth will be a useless waste of money.

The present depth of lake harbors is about 17 to 20 feet, to maintain which requires considerable dredging annually.

The deeper these harbors are made the greater will be the distance into the lake that the cutting in the lake bottom must be made. The effect of wind and wave action is to erode large amounts of material along the shore and to generate littoral currents parallel to the coast, which transport the eroded material until deposited in quiet water. The result is that deep cuts in the bed of the lake fill up rapidly during heavy storms and become more expensive to maintain as the depth of cutting is increased.

With deep cuts at harbor entrances it may be necessary to protect the channel from filling with parallel jetties extending into the lake the full length of the excavation.

## ESTIMATES.

*Intermediate lake channels.*

| | 30-foot channel. | 21-foot channel. |
|---|---|---|
| LAKE SUPERIOR TO LAKE ERIE. | | |
| *Standard low stage of Lake Erie.* | | |
| St. Marys River | $16,605,685 | $5,586,228 |
| Lake Huron | 2,474,135 | 359,488 |
| St. Clair River | 681,943 | 55,281 |
| Lake St. Clair | 3,576,679 | 827,073 |
| Detroit River | 13,786,269 | 1,412,735 |
| Lake Erie | 651,802 | 53,670 |
| | 37,776,513 | 8,294,475 |
| Engineering, superintendence, and contingencies, 10 per cent | 3,777,651 | 829,448 |
| Total | 41,554,164 | 9,123,923 |
| *Regulated stage of Lake Erie.* | | |
| St. Marys River | 15,739,383 | 4,995,799 |
| Lake Huron | 2,176,917 | 248,962 |
| St. Clair River | 494,285 | 37,343 |
| Lake St. Clair | 2,942,846 | 317,017 |
| Detroit River | 8,779,431 | 729,804 |
| Lake Erie | 357,928 | |
| | 30,490,790 | 6,328,925 |
| Engineering, superintendence, and contingencies, 10 per cent | 3,049,079 | 632,893 |
| Total | 33,539,869 | 6,961,818 |
| LAKE MICHIGAN TO LAKE ERIE. | | |
| *Standard low stage of Lake Erie.* | | |
| Lake Huron | 2,474,135 | 359,488 |
| St. Clair River | 681,943 | 55,281 |
| Lake St. Clair | 3,576,679 | 827,073 |
| Detroit River | 13,786,269 | 1,412,735 |
| Lake Erie | 651,802 | 53,670 |
| | 21,170,828 | 2,708,247 |
| Engineering, superintendence, and contingencies, 10 per cent | 2,117,083 | 270,825 |
| Total | 23,287,911 | 2,979,072 |
| *Regulated stage of Lake Erie.* | | |
| Lake Huron | 2,176,917 | 248,962 |
| St. Clair River | 494,285 | 37,343 |
| Lake St. Clair | 2,942,846 | 317,017 |
| Detroit River | 8,779,431 | 729,804 |
| Lake Erie | 357,928 | |
| | 14,751,407 | 1,333,126 |
| Engineering, superintendence, and contingencies, 10 per cent | 1,475,141 | 133,313 |
| Total | 16,226,548 | 1,466,439 |

## COMPARISON OF WATERWAYS.

The channels through the upper lakes and connecting rivers, with the exception of a few short reaches, have greater surface widths than are necessary for either 21 or 30 foot waterways, making the essential difference in the lake routes to be constructed one of depth; but for the waterways from the lakes to the seaboard the dimensions of the prisms of the channels should have a fixed relation to the cross sections of the ships best adapted to the traffic.

The natural depths of harbor entrances and of the lake channels at the foot of Lake Superior, through the St. Marys River, Lake St. Clair, the mouth of Detroit River, and at the head of Lake Erie are such that for waterways more than 21 feet deep excavation will be required for about 60 miles along the route, making 21 feet the limiting depth at which the fixed charges for maintenance and interest on the cost of construction of deeper channels will probably exceed any returns which may be expected from lower rates of transportation in waterways of greater depth. The rate at which freight can be carried on the lakes depends largely upon the probable useful life of the ships constructed for the service, and since continual changes in the dimensions of waterways render the smaller ships practically obsolete long before they are worn out, it is very desirable that the depths to be given the lake waterways should be established and the improvements completed as soon as possible.

Referring to the results of the investigations discussed in the paper on comparison of waterways in Appendix No. 5, it will be noted that for lake channels of greater depth than 21 feet the interest on the cost of the improvement will be much greater than the resulting decrease in the annual cost of transportation of the lake commerce due to deeper channels, and that the project for the improvement of lake channels now being carried out contemplates a depth of 21 feet through the lakes and connecting waterways. If the indirect benefits from the development of new industries around the lakes due to deeper waterways are not greatly in excess of the direct benefits to be derived, there seems to be no legitimate reason why the channels resulting from the project for a 21-foot waterway, when given a proper width and alignment, should not be of as great value to the producers of the country as any waterway of greater depth.

The investigation of the routes for a waterway between Lake Erie and Lake Ontario indicates that the Lasalle-Lewiston line can be constructed at less cost than the others, and can be traversed by a type carrier between points common to all the routes in less time than by the other routes.

The natural harbor at the mouth of the Niagara River and the comparatively small amount of restricted channel on the Lewiston line make it a better location on which to construct a waterway than the route from Tonawanda to Olcott.

The route from Lake Ontario to New York is 208 miles farther by the St. Lawrence River, Lake Champlain, and the Hudson River than by the Oswego, Mohawk, and Hudson rivers, but has 292 feet less lockage than the Mohawk low-level and 366 feet less lockage than the Mohawk high-level routes.

The length of standard canal prism is practically the same by each route, the difference in distance being almost entirely in the open lake and river portions of the waterways.

The sailing time for a type carrier is 12 hours longer for the Champlain route than for the Mohawk route, which difference is due to the greater time required to sail 208 miles farther by the former than to make 18 more lockages on the latter.

The comparative values of the two routes depend largely upon the cost to construct and maintain the respective channels, the annual traffic capacity of each, and the time required for type carriers to make round trips, the details of which are given in the annexed tables.

The estimated cost of the 21-foot waterway and the sailing times between terminals given in the tables are based on locks 600 feet long and 60 feet wide. If the locks should be made 80 feet wide for the purpose of passing large ships from the lake shipyards to the Atlantic, the estimated cost of the Mohawk route would be increased $4,221,000 and the Champlain route $2,560,000, the annual capacity of the routes slightly diminished, and the time required for making round trips increased.

*Table of distances, alignment, width of channel, sailing time, and water levels.*

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Duluth. | | Elevation of water surface. *a* | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| Duluth L. H | Head of St. Marys River | 385.05 | | | Open lake | 385.05 | | 600.1 | Lake Superior. |
| Zero | 42 | .80 | | Tan | 600 feet | | | | St. Marys River. |
| 42 | 73 | | .59 | 44′ | do | | | | |
| 73 | 120 | | .89 | 56′ | do | | | | |
| 120 | 228 | 2.05 | | Tan | do | | | | |
| 228 | 268 | | .76 | 1° | do | | | | |
| 268 | 293+50 | .48 | | Tan | do | | | | |
| 293+50 | 320 | | .50 | 48′ | do | | | | |
| 320 | 425+50 | 1.96 | | Tan | do | | | | |
| 425+50 | 449+50 | | .49 | 48′ | do | | | | |
| 449+50 | 550 | 1.90 | | Tan | do | 395.47 | 31 41 | | |
| 550 | 603+37 | 1.01 | | | | | | 600.1 | Upper approach. |
| 603+37 | 611+37 | .15 | | | | | | | Lock at Saint Ste. Marie. |
| 611+37 | 620 | .16 | | | | | | 582.3 | Lower approach. |
| 620 | 703+30 | 1.58 | | Tan | 600 feet | | | 582.0 | Station 680. |
| 703+30 | 747 | | .83 | 1° | do | | | | |
| 747 | 886 | 2.63 | | Tan | do | | | 581.1 | Station 886. |
| 886 | 898 | | .23 | 44′ | do | | | | |
| 898 | 957 | 1.12 | | Tan | do | | | | |
| 957 | 975 | | .34 | 48′ | do | | | | |
| 975 | 1279 | 5.76 | | Tan | do | | | 580.9 | Station 990. |
| 1279 | 1319 | | .76 | 40′ | do | | | | |
| 1319 | 1502 | 3.48 | | Tan | do | | | | |
| 1502 | 1544 | | .79 | 1° | do | | | | |
| 1544 | 1655 | 2.10 | | Tan | do | | | 580.9 | Station 1566. |
| 1655 | 1695+50 | | .77 | 42′ | do | | | 580.0 | Station 1604. |
| 1695+50 | 1776 | 1.52 | | Tan | do | | | | |
| 1776 | 1849 | | .81 | 1° | do | | | | Winter Point. |
| 1849 | 2282 | 8.78 | | Tan | do | | | | |
| 2282 | 2334 | | .97 | 1° | do | | | | Point Aux Frenes. |
| 2334 | 2490 | 2.95 | | Tan | 600 feet | | | | |
| 2490 | Detour L. H | 11.75 | | | Open river | 443.96 | 39 17 | | |
| Detour L. H | Presque Isle L. H | 47.00 | | | Open lake | 490.96 | 43 03 | | Lake Huron. |
| Presque Isle L. H | Zero | 167.94 | | | do | | | | |
| Zero | 249 | 4.72 | | Tan | 800 feet | | | | |
| 249 | 267 | | .34 | 1° 06′ | do | 663.96 | 56 56 | 580.0 | Fort Gratiot L. H., Station 267. |

*a* Elevations of water surface are those for regulated stage of Lake Erie and standard low water of Lake Superior, and are given immediately above and below locks unless otherwise noted.

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Duluth. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 267 | 283 | | .30 | 1° 06′ | 800 feet | | | | St. Clair River. |
| 283 | 348 | | 1.23 | 1° 06′ | 600 feet | | | 579.7 | Station 303. |
| 348 | 369 | .40 | | Tan | do | | | | |
| 369 | 438 | | 1.31 | 1° | do | | | | |
| 438 | 483 | .85 | | Tan | do | | | | Port Huron. |
| 483 | 526 | | .81 | 20′ | do | | | 578.9 | Station 519. |
| 526 | 583 | | 1.08 | 30′ | do | | | | |
| 583 | 713 | 2.46 | | Tan | do | | | 578.5 | Station 695. |
| 713 | 761 | | .91 | 30′ | do | | | | |
| 761 | 871 | 2.08 | | Tan | do | | | | |
| 871 | 955 | 1.59 | | 26′ | do | | | | |
| 955 | 995 | | .76 | 50′ | do | | | 578.0 | St. Clair, Station 990. |
| 995 | 1035 | .76 | | Tan | do | | | | |
| 1035 | 1060 | | .47 | 50′ | do | | | | |
| 1060 | 1155 | 1.80 | | Tan | do | | | | |
| 1155 | 1237 | | 1.55 | 28′ | do | | | | |
| 1237 | 1562 | 6.16 | | Tan | do | | | 577.3 | Marine City, Station 1402. |
| 1562 | 1632 | | 1.33 | 26′ | do | | | | |
| 1632 | 1662 | | .57 | 40′ | do | | | | |
| 1662 | 1737 | 1.42 | | Tan | do | | | | |
| 1737 | 1757 | | .38 | 42′ | do | | | | |
| 1757 | 1787 | .57 | | Tan | do | | | 576.8 | Algonac, Station 1781. |
| 1787 | 1828 | | .78 | 40′ | do | | | | |
| 1828 | 1891 | 1.19 | | Tan | do | | | | |
| 1891 | 1949 | | .53 | 42′ | do | | | | |
| 1949 | 1952 | | .03 | 36′ | do | | | | |
| 1952 | 2001 | .93 | | Tan | do | | | | |
| 2001 | 2053+50 | | .99 | 46′ | do | | | | |
| 2053+50 | 2143+50 | | 1.70 | 1°10′ | do | | | | |
| 2143+50 | 2163+50 | | .38 | 1° | do | | | | |
| 2163+50 | 2245+50 | | 1.55 | 1° | do | | | | |
| 2245+50 | 2283+50 | .91 | | Tan | do | | | | |
| 2283+50 | 2313+50 | | .38 | 40′ | do | | | | |
| 2313+50 | 2352 | .73 | | Tan | do | 703.45 | | 576.6 | Upper end United States ship canal. Station 2352. |
| 2352 | 2424+15 | 1.37 | | Tan | do | 704.82 | 60 22 | 576.5 | Lower end United States ship canal. Station 2424+15. |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Duluth. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From | To | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 2424+15 | 3201+15 | 14.71 | | Tan | 600 feet | | | | Lake St. Clair. |
| 3201+15 | 3254+15 | | .62 | 36′ | do | | | | |
| 3254+15 | 3312+15 | 1.48 | | Tan | do | 721.63 | 62 00 | 576.1 | Windmill Point Light-House. Station 3312+15. |
| 3312+15 | 3339+15 | .51 | | Tan | do | | | | Detroit River. |
| 3339+15 | 3371+15 | | .61 | 52′ | do | | | | |
| 3371+15 | 3394+15 | .44 | | Tan | do | | | | |
| 3394+15 | 3442+15 | | .91 | 52′ | do | | | | |
| 3442+15 | 3622+15 | 3.41 | | Tan | do | | | | Detroit. |
| 3622+15 | 3842+15 | | 4.17 | 15′ | do | | | 575.9 | Station 3732+15. |
| 3842+15 | 3973+15 | 2.48 | | Tan | do | | | | |
| 3973+15 | 3991+15 | | .34 | 52′ | do | | | | |
| 3991+15 | 4020+15 | .55 | | Tan | do | | | | |
| 4020+15 | 4077+15 | | 1.08 | 1° | do | | | | |
| 4077+15 | 4082+15 | .10 | | Tan | do | | | | |
| 4082+15 | 4118+15 | | .68 | 1° | do | | | | |
| 4118+15 | 4148+15 | .57 | | Tan | do | | | | |
| 4148+15 | 4177+15 | | .55 | 52′ | do | | | | |
| 4177+15 | 4202+15 | .47 | | Tan | do | | | | |
| 4202+15 | 4253+15 | | .59 | 52′ | do | | | 575.8 | Wyandotte, Station 4210. |
| 4253+15 | 4252+15 | .36 | | Tan | do | | | | |
| 4252+15 | 4297+15 | | .85 | 50′ | do | | | | |
| 4297+15 | 4433+65 | 2.59 | | Tan | do | | | | |
| 4433+65 | 4460+65 | | .51 | 28′ | do | | | | |
| 4460+65 | 4580+65 | 2.46 | | Tan | do | | | 574.8 | Station 4580+65. |
| 4580+65 | 4610+65 | | .38 | 1° | do | 746.23 | 64 03 | | Bois Blanc, L. H. |
| 4610+65 | 4730+65 | 2.27 | | Tan | do | | | | |
| 4730+65 | 4917+15 | 3.53 | | Tan | 800 feet | | | 574.5 | Station 4730. |
| 4917+15 | 5112+15 | 3.69 | | Tan | do | | | | Lake Erie. |
| 5112+15 | —39 | 233.02 | | | Open lake | | | | |
| —39 | Zero at Buffalo | .74 | | | | 989.48 | 83 40 | 574.5 | Station zero, regulating works, head of Niagara River, Buffalo, N. Y. |
| Duluth | Buffalo | 951.49 | 37.99 | | | 989.48 | 83 40 | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

FROM CHICAGO TO BUFFALO.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Duluth. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| Chicago lights | Presque Isle, L. H. | 392.07 | | | Open lake | 392.07 | 31 22 | 580.0 | Lakes Michigan and Huron. |
| Presque Isle, L. H. | Zero at Buffalo | 498.52 | | | | 890.59 | 71 59 | | For details see Duluth Buffalo route. |
| Chicago | Buffalo | | | | | 890.59 | 71 59 | | |

LASALLE-LEWISTON ROUTE.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. *a* | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| | Zero | | | | | | | | Regulating works, head of Niagara River, Buffalo, N. Y. |
| Zero | 13+50 | 0.25 | | Tan | 600 feet | | | | Niagara River. |
| 13+50 | 18 | .09 | | Tan | 420 feet | | | | |
| 18 | 27 | | 0.17 | 30′ | do | | | | |
| 27 | 40 | | .25 | 30′ | Standard | | | | |
| 40 | 69 | .55 | | Tan | do | | | | |
| 69 | 85+07 | .30 | | | | | | 574.5 | Upper approach. |
| 85+07 | 91+07 | .11 | | | | 1.72 | | | Lock No. 1. |
| 91+07 | 107+01 | .30 | | | | | | 566.5 | Lower approach. |
| 107+01 | 108+71 | .03 | | Tan | Standard | | | | |

*a* Elevations of water surface are those for a regulated stage of Lake Erie and a standard low water of Lake Ontario, and are given immediately above and below locks unless otherwise noted. Elevations referred to Buffalo bench mark.

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

LASALLE-LEWISTON ROUTE—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From | To | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 108+71 | 127 | | .35 | 1° | Standard | | | | |
| 127 | 144 | .32 | | Tan | do | | | | |
| 144 | 152 | .15 | | Tan | 600 feet | | | | |
| 152 | 180+50 | | .54 | 1° | do | | | | |
| 180+50 | 195 | .28 | | Tan | do | | | | |
| 195 | 240 | | .85 | 1° | do | | | | |
| 240 | 300 | 1.14 | | Tan | do | | | | |
| 300 | 480 | | 3.41 | 45′ | do | | | | |
| 480 | 534+10 | 1.03 | | Tan | do | 10.12 | | | Tonawanda. |
| 534+10 | 593+80 | | 1.13 | 1° 16′ | do | | | | |
| 593+80 | 611 | .32 | | Tan | do | | | | |
| 611 | 734 | | 2.33 | 30′ | do | | | | |
| 734 | 763+30 | | .55 | 1° | do | | | | |
| 763+30 | 818+60 | 1.04 | | Tan | do | | | | |
| 818+60 | 827+00 | | 17 | 30′ | do | 15.66 | 2 40 | | Lasalle. |
| 827 | 839+69 | | .24 | 30′ | Standard | | | | |
| 839+69 | 1171+10 | 6.28 | | Tan | do | | | | |
| 1171+10 | 1194+23 | | .44 | 40′ | do | | | | |
| 1194+23 | 1212 | .34 | | Tan | do | | | | |
| 1212 | 1218+07 | .11 | | | | | | 563.5 | Upper approach. |
| 1218+07 | 1254+07 | .68 | | | | | | | Locks Nos. 2, 3, 4, 5, 6, and 7. |
| 1254+07 | 1283+67 | .56 | | | 170 feet | | | 323.5 | Basin. |
| 1283+67 | 1295+67 | .23 | | | | | | | Locks Nos. 8 and 9. |
| 1295+67 | 1301+61 | .11 | | | | 24.65 | 6 45 | 244.7 | Lower approach. |
| 1301+61 | 1655 | 6.70 | | | Open river | | | | Mouth of Niagara River. |
| 1655 | Lake Ontario Junction | 33.44 | | | Open lake | 64.79 | 9 58 | | Lake Ontario. |
| Buffalo | do | 54.36 | 10.43 | | | 64.79 | 9 58 | | |

*Table of distances, alignment, width of channel, sailing time, and water levels.*

OSWEGO-MOHAWK ROUTE, LOW LEVEL.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| Buffalo | Lake Ontario Junction | 54.36 | 10.43 | | | 64.79 | 9 58 | | (For details see Lasalle-Lewiston route.) |
| Lake Ontario Junction. | —27 | 98.60 | | | Open lake | 163.39 | 17 52 | 245.4 | End of breakwater, Oswego. |
| —27 | —6+80 | .38 | | | | | | 245.4 | Lower approach. |
| —6+80 | —0+80 | .11 | | | | | | | Lock No. 1. |
| —0+80 | 5+50 | .12 | | | | | | 266.8 | Upper approach. |
| 5+50 | 25+40 | .38 | | Tan | Standard | | | | Basin. |
| 25+40 | 34+20 | .17 | | | | | | 266.8 | Lower approach. |
| 34+20 | 46+20 | .23 | | | | 164.78 | | | Locks No. 2 and No. 3. |
| 46+20 | 62+50 | .31 | | | | | | 309.6 | Upper approach. |
| 62+50 | 67+28 | .09 | | Tan | Standard | | | | |
| 67+28 | 97+04 | | .56 | 30′ | do | | | | |
| 97+04 | 127+84 | .58 | | Tan | do | | | | |
| 127+84 | 145+56 | | .34 | 30′ | do | | | | |
| 145+56 | 220 | 1.41 | | Tan | do | | | | |
| 220 | 243+50 | | .44 | 40′ | do | | | | |
| 243+50 | 254+20 | .20 | | Tan | do | | | | |
| 254+20 | 272+09 | .34 | | | | | | 309.6 | Lower approach. |
| 272+09 | 278+09 | .11 | | | | | | | Lock No. 4. |
| 278+09 | 289 | .21 | | | | | | 331.0 | Upper approach. |
| 289 | 302+11 | .25 | | Tan | 400 feet | 169.62 | 21 00 | | Oswego River. |
| 302+11 | 313+42 | | .21 | 1° | do | | | | |
| 313+42 | 348+18 | .66 | | Tan | do | | | | |
| 348+18 | 365+36 | | .33 | 1° | do | | | | |
| 365+36 | 391+04 | .49 | | Tan | do | | | | |
| 391+04 | 411+59 | | .39 | 1° | do | | | | |
| 411+59 | 415+86 | .08 | | Tan | do | | | | |
| 415+86 | 461+59 | | .87 | 1° | do | | | | |
| 461+59 | 485+38 | .45 | | Tan | do | | | | |
| 485+38 | 540+31 | | 1.04 | 1° | do | | | | End of Oswego River. |
| 540+31 | 549+50 | .17 | | Tan | do | | | | |
| 549+50 | 565+80 | .31 | | Tan | Standard | | | | Fulton. |
| 565+80 | 583+20 | .33 | | | | | | 331.0 | Lower approach. |
| 583+20 | 589+20 | .11 | | | | 175.06 | | | Lock No. 5. |

*a* Elevations of water surface are those for a low stage of rivers, and are given immediately above and below the locks unless otherwise noted.

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

OSWEGO-MOHAWK ROUTE, LOW LEVEL—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 589+20 | 596+43 | .14 | | | | | | 349.0 | Upper approach. |
| 596+43 | 605+50 | | .17 | 1° 16′ | | | | | Do. |
| 605+50 | 613+76 | | .16 | 1° 16′ | Standard | | | | |
| 613+76 | 628+80 | .28 | | Tan | do | | | | |
| 628+80 | 646+20 | .33 | | | | | | 349.0 | Lower approach. |
| 646+20 | 652+20 | .11 | | | | 176.25 | | | Lock No. 6. |
| 652+20 | 659+65 | .14 | | | | | | 367.0 | Upper approach. |
| 659+65 | 668+50 | | .17 | 1° 16′ | | | | | Do. |
| 668+50 | 681+40 | | .25 | 1° 16′ | Standard | | | | |
| 681+40 | 715+80 | .65 | | Tan | do | | | | |
| 715+80 | 717+37 | .03 | | Tan | do | | | | Lower approach. |
| 717+37 | 723+06 | | .11 | 30′ | | | | | Do. |
| 723+06 | 733+20 | .19 | | | | | | 367.0 | Do. |
| 733+20 | 739+20 | .11 | | | | 177.90 | | | Lock No. 7. |
| 739+20 | 755+50 | .31 | | | | | | 379.0 | Upper approach. |
| 755+50 | 770+04 | .28 | | Tan | Standard | | | | |
| 770+04 | 812+63 | | .81 | 30′ | do | | | | |
| 812+63 | 891+58 Zero | 1.50 | | Tan | do | | | | |
| Zero | 34+28 | | .65 | 30′ | do | | | | Stations 891+58 and 1166+68 of high level line correspond with stations 0 and 267+68 of low-level line, respectively. |
| 34+28 | 129+47 | 1.80 | | Tan | do | | | | |
| 129+47 | 166+53 | | .70 | 30′ | do | | | | |
| 166+53 | 235+32 | 1.30 | | Tan | do | | | | |
| 235+32 | 267+68 1166+68 | | .61 | 1° | do | | | | |
| 1166+68 | 1204+85 | .72 | | Tan | do | | | | |
| 1204+85 | 1277+02 | | 1.37 | 30′ | do | | | | |
| 1277+02 | 1326 | | .93 | 30′ | do | | | | |
| 1326 | 1347+74 | | .41 | 30′ | 400 feet | | | | |
| 1347+74 | 1410 | 1.18 | | Tan | do | 190.47 | 25 33 | 379.0 | Brewerton. |
| 1410 | 1824+28 | 7.85 | | do | 600 feet | | | | Lake Oneida. |
| 1824+28 | 1830+08 | | .11 | 1° | Open lake | | | | |
| 1830+08 | 2467+49 | 12.07 | | Tan | do | | | | |
| 2467+49 | 2483+56 1+06 | | .30 | 1° | do | | | | |
| 1+06 | 30 | .55 | | Tan | do | | | | |
| 30 | 36+50 | .12 | | do | 600 feet | 211.47 | 27 16 | 379.0 | Sylvan Beach, shore of Lake Oneida. |
| 36+50 | 509+41 | 8.96 | | do | Standard | | | | |
| 509+41 | 539+26 | | .56 | 30′ | do | | | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

OSWEGO-MOHAWK ROUTE, LOW LEVEL—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 539+26 | 662+23—3142+95 | 2.53 | | Tan | Standard | | | | |
| 3142+95 | 3190+29 | | .90 | 50° | do | | | | |
| 3190+29 | 3269+44 | 1.50 | | Tan | do | | | | Rome. |
| 3269+44 | 3321+52 | | .99 | 50° | do | | | | |
| 3321+52 | 3497+04 | 3.32 | | Tan | do | | | | |
| 3497+04 | 3503+62 | | 1.83 | 30° | do | | | | |
| 3503+62 | 3866+07 | 5.16 | | Tan | do | | | | |
| 3866+07 | 3923+58 | | 1.09 | 30° | do | | | | |
| 3923+58 | 4208+89 | 5.40 | | Tan | do | | | | Utica. |
| 4208+89 | 4236+87 | | .53 | 30° | do | | | | |
| 4236+87 | 4490+76 | 4.81 | | Tan | do | | | | |
| 4490+76 | 4528+87 | | .72 | 30° | do | | | | |
| 4528+87 | 4534+50 | .11 | | Tan | do | | | | |
| 4534+50 | 4550+79 | .31 | | | | | | 379.0 | Upper approach. |
| 4550+79 | 4556+79 | .11 | | | | 250.10 | | | Lock No. 10. |
| 4556+79 | 4574+20 | .32 | | | | | | 376.0 | Lower approach. |
| 4574+20 | 4590+18 | .30 | | Tan | do | | | | |
| 4590+18 | 4626+77 | | .69 | 40° | do | | | | |
| 4626+77 | 4664+36 | .71 | | Tan | do | | | | |
| 4664+36 | 4724+28 | | 1.14 | 40° | do | | | | |
| 4724+28 | 4789+92 | 1.25 | | Tan | do | 254.51 | | | Herkimer, N. Y. |
| 4789+92 | 4846+74 | 1.08 | | Tan | do | | | | |
| 4846+74 | 4850+92 | | .08 | 30° | do | | | | |
| 4850+92 | 4874+36 | | .44 | 30° | 202 feet | | | | |
| 4874+36 | 4919+92 | .86 | | Tan | do | | | | |
| 4919+92 | 4935+99 | .31 | | | | | | 376.0 | Upper approach. |
| 4935+99 | 4941+99 | .11 | | | | 257.39 | | | Lock No. 11. |
| 4941+99 | 4957+92 | .30 | | | | | | 365.0 | Lower approach. |
| 4957+92 | 5001+46 | .82 | | Tan | 267 feet | | | | |
| 5001+46 | 5066+52 | | 1.23 | 40° | do | | | | |
| 5066+52 | 5119+42 | 1.00 | | Tan | do | | | | |
| 5119+42 | 5127+68 | .16 | | Tan | Standard | | | | |
| 5127+68 | 5143+92 | | .31 | 1° 50′ | do | | | | Little Falls. |
| 5143+92 | 5158+99 | .29 | | | | | | 365.0 | Upper approach. |
| 5158+99 | 5170+99 | .23 | | | | | | | Locks Nos. 12 and 13. |
| 5170+99 | 5194+92 | .45 | | | | 262.18 | 35 47 | 322.0 | Lower approach. |
| 5194+92 | 5238+88 | .83 | | Tan | 267 feet | | | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

OSWEGO-MOHAWK ROUTE, LOW LEVEL—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 5238+88 | 5274+12 | | .67 | 30′ | 267 feet | | | | |
| 5274+12 | 5313+90 | .75 | | Tan | do | | | | |
| 5313+90 | 5353+84 | | .38 | 30′ | do | | | | |
| 5353+84 | 5480+92 | 2.79 | | Tan | do | | | | |
| 5480+92 | 5487+04 | .12 | | Tan | 341 feet | | | | |
| 5487+04 | 5511+41 | | .46 | 30′ | do | | | | |
| 5511+41 | 5532+82 | | .40 | 30′ | Standard | | | | |
| 5532+82 | 5542+02 | .19 | | Tan | do | | | | |
| 5542+02 | 5558+90 | .31 | | | | | | 322.0 | Upper approach. |
| 5558+90 | 5564+90 | .11 | | | | 269.19 | | | Lock No. 14. |
| 5564+90 | 5592+92 | .53 | | | | | | 300.0 | Lower approach. |
| 5592+92 | 5671+86 | 1.50 | | Tan | 321 feet | | | | |
| 5671+86 | 5721+82 | | .95 | 1° | do | | | | |
| 5721+82 | 5807+32 | 1.62 | | Tan | do | | | | |
| 5807+32 | 5820+42 | | .25 | 30′ | do | | | | |
| 5820+42 | 5836+94 | | .31 | 30′ | 364 feet | | | | |
| 5836+94 | 5981+72 | 2.74 | | Tan | do | | | | |
| 5981+72 | 6016+92 | | .67 | 1° | do | | | | |
| 6016+92 | 6022+50 | | .10 | 1° | | | | | Upper approach. |
| 6022+50 | 6032+80 | .20 | | | | | | 300.0 | Do. |
| 6032+80 | 6038+90 | .11 | | | | 278.17 | | | Lock No. 15. |
| 6038+90 | 6054+92 | .30 | | | | | | 285.0 | Lower approach. |
| 6054+92 | 6069+88 | .28 | | Tan | 329 feet | | | | |
| 6069+88 | 6089+26 | | .55 | 1° | do | | | | |
| 6089+26 | 6118+72 | .37 | | Tan | do | | | | |
| 6118+72 | 6149+76 | | .59 | 50′ | do | | | | |
| 6149+76 | 6251+72 | 1.93 | | Tan | do | | | | |
| 6251+72 | 6282+78 | | .59 | 1° | do | | | | |
| 6282+78 | 6386+30 | 1.96 | | Tan | do | | | | |
| 6386+30 | 6390+42 | | .09 | 1°45′ | do | | | | |
| 6390+42 | 6424+20 | | .64 | 1°45′ | 290 feet | | | | |
| 6424+20 | 6440+98 | .32 | | Tan | do | | | | |
| 6440+98 | 6469+84 | | .55 | 30′ | do | | | | |
| 6469+84 | 6616+32 | 2.77 | | Tan | do | | | | |
| 6616+32 | 6643+64 | | .52 | 30′ | do | | | | |
| 6643+64 | 6660+92 | .33 | | Tan | do | | | | |
| 6660+92 | 6676+99 | .30 | | | | | | 285.0 | Upper approach. |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

OSWEGO-MOHAWK ROUTE, LOW LEVEL—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 6676+99 | 6682+99 | .11 | | | | 290.37 | | | Lock No. 16. |
| 6682+99 | 6700+62 | .33 | | | | | | 270.0 | Lower approach. |
| 6700+62 | 6706+08 | .10 | | Tan | 290 feet | | | | |
| 6706+08 | 6771+18 | | 1.23 | 50′ | do | | | | Fonda. |
| 6771+18 | 6867+96 | 1.83 | | Tan | do | | | | |
| 6867+96 | 6947+04 | | 1.50 | 50′ | do | | | | |
| 6947+04 | 6989+42 | .80 | | Tan | do | | | | |
| 6989+42 | 6996+92 | .14 | | Tan | 406 feet | | | | |
| 6996+92 | 7069+44 | | 1.38 | 30′ | do | | | | |
| 7069+44 | 7140+64 | 1.35 | | Tan | do | | | | |
| 7140+64 | 7180+64 | | .76 | 1° | do | | | | |
| 7180+64 | 7194+92 | .27 | | Tan | do | | | | |
| 7194+92 | 7210+99 | .31 | | | | | | 270.0 | Upper approach. |
| 7210+99 | 7216+99 | .11 | | | | 300.48 | | | Lock No. 17. |
| 7216+99 | 7225+18 | .16 | | | | | | 255.0 | Lower approach. |
| 7225+18 | 7230+62 | | .10 | 1° | | | | | Do. |
| 7230+62 | 7240+38 | | .18 | 1° | 460 feet | | | | |
| 7240+38 | 7260+92 | .39 | | Tan | do | | | | Amsterdam. |
| 7260+92 | 7272+02 | | .21 | 1° | do | | | | |
| 7272+02 | 7292+20 | .38 | | Tan | do | | | | |
| 7292+20 | 7345+88 | | 1.02 | 30′ | do | | | | |
| 7345+88 | 7423+38 | 1.47 | | Tan | do | | | | |
| 7423+38 | 7439+44 | | .30 | 30′ | do | | | | |
| 7439+44 | 7445+06 | | .11 | 30′ | | | | | Upper approach. |
| 7445+06 | 7455+52 | .20 | | | | | | 255.0 | Do. |
| 7455+52 | 7461+52 | .11 | | | | 305.11 | | | Lock No. 18. |
| 7461+52 | 7479+16 | .33 | | | | | | 240.0 | Lower approach. |
| 7479+16 | 7484 | .09 | | Tan | 460 feet | | | | |
| 7484 | 7508+48 | | .47 | 30′ | do | | | | |
| 7508+48 | 7535+30 | .51 | | Tan | do | | | | |
| 7535+30 | 7558+48 | | .44 | 1° | do | | | | |
| 7558+48 | 7614+25 | 1.06 | | Tan | do | | | | |
| 7614+25 | 7665+55 | | .97 | 15′ | do | | | | |
| 7665+55 | 7705+21 | .75 | | Tan | do | | | | |
| 7705+21 | 7731+30 | | .50 | 1° | do | | | | |
| 7731+30 | 7737+30 | | .11 | 1° | Standard | | | | |
| 7737+30 | 7739+45 | | .04 | 1° | | | | | Upper approach. |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

OSWEGO-MOHAWK ROUTE, LOW LEVEL—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 7739+45 | 7748+41 | .17 | | | | | | 240.0 | Upper approach. |
| 7748+41 | 7754+41 | .11 | | | | | | | Lock No. 19 (guard lock). |
| 7754+41 | 7765+30 | .21 | | | | | | 240.0 | Lower approach. |
| 7765+30 | 7801+70 | .69 | | Tan | Standard | 311.56 | 44 35 | | |
| 7801+70 | 7824+66 | | .44 | 30′ | do | | | | |
| 7824+66 | 7909+82 | 1.61 | | Tan | do | | | | |
| 7909+82 | 7975+65 | | 1.25 | 30′ | do | | | | |
| 7975+65 | 7986+25 | .20 | | Tan | do | | | | |
| 7986+25 | 8031+15 | | .85 | 1° | do | | | | |
| 8031+15 | 8047+09 | .30 | | Tan | do | | | | |
| 8047+09 | 8080+04 | | .62 | 1° | do | | | | |
| 8080+04 | 8152+90 | 1.38 | | Tan | do | | | | |
| 8152+90 | 8184+48 | | .60 | 30′ | do | | | | |
| 8184+48 | 8284+17 | 1.89 | | Tan | do | | | | |
| 8284+17 | 8322+71 | | .73 | 1° | do | | | | |
| 8322+71 | 8387+69 | 1.23 | | Tan | do | | | | |
| 8387+69 | 8403+76 | .30 | | | | | | 240.0 | Upper approach. |
| 8403+76 | 8409+76 | .11 | | | | 323.07 | | | Lock No. 20. |
| 8409+76 | 8422+69 | .25 | | Tan | | | | 225.0 | Lower approach. |
| 8422+69 | 8423+57 | .02 | | Tan | Standard | | | | |
| 8423+57 | 8425+12 | | .03 | 30′ | do | | | | |
| 8425+12 | 8440+63 | | .29 | 30′ | Open river | | | | Norman's Kill. |
| 8440+63 | 8482+18 | .79 | | Tan | Open river | | | | |
| 8482+18 | 8484+18 | .04 | | Tan | Half open / Half standard | | | | |
| 8484+18 | 8491+69 | .14 | | Tan | Standard | | | | |
| 8491+69 | 8507+76 | .30 | | Tan | | | | 225.0 | Upper approach. |
| 8507+76 | 8513+76 | .11 | | | | 325.04 | | | Lock No. 21. |
| 8513+76 | 8524+02 | .19 | | | | | | 205.0 | Lower approach. |
| 8524+02 | 8524+69 | | .01 | 1° | | | | | Do. |
| 8524+69 | 8535+19 | | .20 | 1° | Half open / Half standard | | | | |
| 8535+19 | 8537+17 | | .04 | 1° | Standard | | | | |
| 8537+17 | 8548+76 | .22 | | | | | | 205.0 | Upper approach. |
| 8548+76 | 8560+76 | .23 | | | | 325.93 | | | Locks Nos. 22 and 23. |
| 8560+76 | 8576+70 | .30 | | | | | | 165.0 | Lower approach. |
| 8576+70 | 8582+25 | .11 | | Tan | Open river | | | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

OSWEGO-MOHAWK ROUTE, LOW LEVEL—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 8582+25 | 8614+14 | | .60 | 1° 15′ | Open river | | | | |
| 8614+14 | 8617+19 | .06 | | Tan | do | | | | |
| 8617+19 | 8622+22 | .10 | | Tan | Half open<br>Half standard | | | | |
| 8622+22 | 8623+95 | | .03 | 1° 15′ | Half open<br>Halt standard | | | | |
| 8623+95 | 8644+68 | | .39 | 1° 15′ | Open river | | | | |
| 8644+68 | 8649+47 | | .09 | 1° 15′ | Half open<br>Half standard | | | | |
| 8649+47 | 8650+28 | | .02 | 1° 15′ | Open river | | | | |
| 8650+28 | 8658+19 | .15 | | Tan | do | | | | |
| 8658+19 | 8662+19 | .08 | | Tan | Half open<br>Half standard | | | | |
| 8662+19 | 8675+19 | .25 | | Tan | Open river | | | | |
| 8675+19 | 8677+19 | .04 | | Tan | Half open<br>Half standard | | | | |
| 8677+19 | 8694+69 | .33 | | Tan | Standard | | | | |
| 8694+69 | 8698+69 | .08 | | Tan | Half open<br>Half standard | | | | |
| 8698+69 | 8714+19 | .29 | | Tan | Open river | | | | |
| 8714+19 | 8716+18 | .04 | | Tan | Half open<br>Half standard | | | | |
| 8716+18 | 8732+19 | .30 | | Tan | Open river | | | | |
| 8732+19 | 8743+86 | .22 | | Tan | Standard | | | | |
| 8743+86 | 8746+19 | | .04 | 30′ | do | | | | |
| 8746+19 | 8751+61 | | .10 | 30′ | Half open<br>Half standard | | | | |
| 8751+61 | 8752+65 | .02 | | Tan | Half open<br>Half standard | | | | |
| 8752+65 | 8777+69 | .47 | | Tan | Open river | | | | |
| 8777+69 | 8781+82 | .08 | | Tan | Half open<br>Half standard | | | | |
| 8781+82 | 8792+19 | | .20 | 50′ | Half open<br>Half standard | | | | |
| 8792+19 | 8806+42 | | .27 | 50′ | Standard | | | | |
| 8806+42 | 8824+69 | .35 | | Tan | do | | | | |
| 8824+69 | 8841+39 | .32 | | Tan | Open river | | | | |
| 8841+39 | 8860+92 | | .37 | 50′ | do | | | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

OSWEGO-MOHAWK ROUTE, LOW LEVEL—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From | To | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 8850+92 | 8895+60 | .66 | | Tan | Open river | | | | |
| 8895+60 | 8899+19 | | .07 | 1°15′ | do | | | | |
| 8899+19 | 8913+69 | | .27 | 1°15′ | Standard | | | | |
| 8913+69 | 8915+69 | | .04 | 1°15′ | Open river | | | | |
| 8915+69 | 8925+19 | | .18 | 1°15′ | Half open<br>Half standard | | | | |
| 8925+19 | 8925+95 | | .01 | 1°15′ | Open river | | | | |
| 8925+95 | 8927+69 | .03 | | Tan | do | | | | |
| 8927+69 | 8943+76 | .30 | | | | | | 165.0 | Upper approach. |
| 8943+76 | 8961+76 | .34 | | | | 333.53 | | | Locks Nos. 24, 25, and 26. |
| 8961+76 | 8973+69 | .22 | | | | | | 103.5 | Lower approach. |
| 8973+69 | 8973+87 | .00 | | Tan | Open river | | | | |
| 8973+87 | 8979+69 | | .11 | 1°15′ | Standard | | | | |
| 8979+69 | 8993+69 | .27 | | Tan | do | | | | |
| 8993+69 | 8995+44 | .03 | | Tan | Open river | | | | |
| 8995+44 | 9005+52 | .19 | | Tan | Half open<br>Half standard | | | | |
| 9005+52 | 9021+59 | .30 | | | | | | 103.5 | Upper approach. |
| 9021+59 | 9051+59 | .57 | | | | | | | Locks Nos. 27, 28, 29, 30, and 31. |
| 9051+59 | 9059+82 | .16 | | | | | | 0.2 | Lower approach. |
| 9059+82 | 9087+69 | | .53 | 1°28′26″ | | | | | Do. |
| 9087+69 | 9106+18—5757 | | .35 | 1°28′26″ | Open river | 336.26 | 52 21 | 0.2 | Station 5757. Mouth of Normans Kill Hudson River. |
| Buffalo | Hudson River | 278.62 | 57.64 | | | 336.26 | 52 21 | | At mouth of Normans Kill. |
| 5757+00 | 5775+66 | | .35 | 38′ | 400 feet | | | | |
| 5775+66 | 5789+45 | .26 | | Tan | do | | | | |
| 5789+45 | 5806+93 | | .33 | 25′ | do | | | | |
| 5806+93 | 5820 | .25 | | Tan | do | | | | |
| 5820 | 5848+20 | | .34 | 40′ | do | | | | |
| 5848+20 | 5856+31 | .34 | | Tan | do | | | | |
| 5856+31 | 5876+14 | | .38 | 1° | do | | | | |
| 5876+14 | 5897+91 | .41 | | Tan | do | | | | |
| 5897+91 | 5905+70 | | .15 | 40′ | do | | | | |
| 5905+70 | 5918+79 | | .25 | 40′ | 600 feet | | | | |
| 5918+79 | 5964+40 | .86 | | Tan | do | | | | |
| 5964+40 | 5981+07 | | .32 | 15′ | do | | | | |
| 5981+07 | 6023+65 | .81 | | Tan | do | | | | |
| 6023+65 | 6049+75 | | .49 | 30′ | do | | | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

OSWEGO-MOHAWK ROUTE, LOW LEVEL—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 6049+75 | 6067+59 | .34 | | Tan | 600 feet | | | | |
| 6067+59 | 6093+49 | | .49 | 30′ | do | | | | |
| 6093+49 | 6116+47 | .44 | | Tan | do | | | | |
| 6116+47 | 6134+43 | | .34 | 30′ | do | | | | |
| 6134+43 | 6211+44 | 1.46 | | Tan | do | | | 0.0 | Station 6198. |
| 6211+44 | 6245 | | .64 | 45′ | do | | | | |
| 6245 | 6264+56 | .37 | | Tan | do | | | | |
| 6264+56 | 6289+23 | | .47 | 30′ | do | | | | |
| 6289+23 | 6296+93 | .15 | | Tan | do | | | | |
| 6296+93 | 6314+03 | | .32 | 1°10′ | do | | | | |
| 6314+03 | 6351+58 | .71 | | Tan | do | | | | |
| 6351+58 | 6379+95 | | .54 | 30′ | do | | | | |
| 6379+95 | 6446+54 | 1.26 | | Tan | do | | | | |
| 6446+54 | 6473+84 | | .52 | 30′ | do | | | | |
| 6473+84 | 6501+34 | .52 | | Tan | do | | | | |
| 6501+34 | 6534+01 | | .62 | 30′ | do | | | | |
| 6534+01 | 6600+22 | 1.25 | | Tan | do | | | | |
| 6600+22 | 6627+82 | | .52 | 1° | do | | | | |
| 6627+82 | 6673+16 | .86 | | Tan | do | | | | |
| 6673+16 | 6687+86 | | .28 | 30′ | do | | | | |
| 6687+86 | 6703+15 | .29 | | Tan | do | | | | |
| 6703+15 | 6723+75 | | .39 | 40′ | do | | | | |
| 7623+75 | 6785+59 | 1.17 | | Tan | do | | | | |
| 6785+59 | 6799+99 | | .27 | 30′ | do | | | | |
| 6799+99 | 6873+50 | 1.39 | | Tan | do | | | | |
| 6873+50 | 6877+23 | .07 | | Tan | Open river | | | | |
| 6877+23 | 6902+70 | | .48 | 30′ | do | | | | |
| 6902+70 | 6924+91 | .42 | | Tan | do | | | | |
| 6924+91 | 6944+44 | | .37 | 1° | do | | | | |
| 6944+44 | 6951+50 | .13 | | Tan | do | | | | |
| 6951+50 | 7059+50 | 2.05 | | Tan | 600 feet | | | | |
| 7059+50 | 7099+54 | .75 | | Tan | Open river | | | −0.8 | Station 7080. |
| 7099+54 | 7129+01 | | .56 | 1° 16′ | do | | | | |
| 7129+01 | Battery | 114.69 | | | do | 476.94 | 64 11 | | New York City. |
| Buffalo | New York | 409.88 | 67.06 | | | 476.94 | 64 11 | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

CHAMPLAIN ROUTE.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs Min.* | | |
| Buffalo | Lake Ontario Junction | 54.36 | 10.43 | | | 64.79 | 9 58 | | For details see Lasalle-Lewiston route. |
| Lake Ontario Junction. | Station 0 at Tibbetts Point | 114.96 | | | Open lake | 179.75 | 19 10 | 245.4 | Tibbetts Point light-house. |
| Zero | 3303 | 62.55 | | | Open river | 242.30 | 24 10 | | Ogdensburg. |
| 3303 | 3574 | 5.13 | | | do | | | | |
| 3574 | 3600+53 | | .50 | 34′ | 600 feet | | | | |
| 3600+53 | 3601+55 | .02 | | Tan | do | | | | |
| 3601+55 | 3643+74 | | .80 | 1° 16′ | do | | | | |
| 3643+74 | 3674+76 | | .59 | 1° 16′ | do | | | | |
| 3674+76 | 3740+73 | 1.25 | | Tan | do | | | | |
| 3740+73 | 3747+17 | .12 | | Tan | 400 feet | | | | |
| 3747+17 | 3763+29 | | .31 | 1° | do | | | | |
| 3763+29 | 3770+83 | | .14 | 1° | | | | | Upper approach. |
| 3770+83 | 3779+36 | .17 | | | | | | 242.7 | Do. |
| 3779+36 | 3785+36 | .11 | | | | 251.44 | | | Lock No. 1. |
| 3785+36 | 3801+30 | .30 | | | | | | 233.0 | Lower approach. |
| 3801+30 | 3856 | 1.04 | | | Open river | | | | |
| 3856 | 3861+14 | | .10 | 1° 16′ | 600 feet | | | | |
| 3861+14 | 3885 | | .45 | 1° 16′ | 400 feet | | | | |
| 3885 | 3909 | 2.16 | | | Open river | | | | |
| 3909 | 4040+13 | | .59 | 1° 10′ | 600 feet | | | | |
| 4040+13 | 4058+92 | .17 | | Tan | do | | | | |
| 4058+92 | 4066 | | .51 | 1° 16′ | do | | | | |
| 4066 | 4209 | 2.71 | | | Open river | | | | |
| 4209 | 4212+80 | .07 | | Tan | 600 feet | | | | |
| 4212+80 | 4250+89 | .72 | | Tan | Standard | | | | |
| 4250+89 | 4274+22 | | .44 | 1° | do | | | | |
| 4274+22 | 4281+30 | .14 | | Tan | do | | | | |
| 4281+30 | 4348 | 1.26 | | Tan | 600 feet | | | | Waddington. |
| 4348 | 4362+10 | .27 | | | Open river | | | | |
| 4362+10 | 4372+86 | .20 | | | | | | 225.7 | Upper approach. |
| 4372+86 | 4378+86 | .11 | | | | 262.68 | | | Lock No. 2. |
| 4378+86 | 4384+83 | .11 | | | | | | 213.9 | Lower approach. |
| 4384+83 | 4400+11 | | .29 | 1° 16′ | | | | | Do. |

*a* Elevations of water surface are those for a low stage of rivers, and are given immediately above and below locks unless otherwise noted.

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

CHAMPLAIN ROUTE—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 4400+11 | 4402+36 | | .04 | 1° 16′ | Standard | | | | |
| 4402+36 | 4422+04 | | .37 | 1° 16′ | 600 feet | | | | |
| 4422+04 | 4438+40 | .31 | | Tan | do | | | | |
| 4438+40 | 4455 | | .31 | 1° 16′ | do | | | | |
| 4455 | 4531 | 1.44 | | | Open river | | | | |
| 4531 | 4535 | .08 | | Tan | 600 feet | | | | |
| 4535 | 4569 | .64 | | | Open river | | | | |
| 4569 | 4578 | .17 | | Tan | 600 feet | | | | |
| 4578 | 4726 | 2.80 | | | Open river | | | | |
| 4726 | 4730+98 | | .10 | 1° 16′ | 600 feet | | | | |
| 4730+98 | 4745+38 | .27 | | Tan | do | | | | |
| 4745+38 | 4748 | | .05 | 50′ | do | | | | |
| 4748 | 4916 | 3.18 | | | Open river | | | | |
| 4916 | 4919 | .06 | | Tan | 600 feet | | | | |
| 4919 | 5055 | 2.58 | | | Open river | | | | |
| 5055 | 5062 | .13 | | Tan | 500 feet | | | | |
| 5062 | 5065 | .06 | | | Open river | | | | |
| 5065 | 5072+30 | .14 | | Tan | 600 feet | | | | |
| 5072+30 | 5101+03 | .54 | | Tan | Standard | | | | |
| 5101+03 | 5110+90 | | .19 | 1° | do | | | | |
| 5110+90 | 5191+58 | 1.53 | | Tan | do | | | | |
| 5191+58 | 5225+98 | | .65 | 1° | do | | | | |
| 5225+98 | 5330+83 | 1.99 | | Tan | do | | | | |
| 5330+83 | 5337+66 | | .13 | 1° | do | | | | |
| 5337+66 | 5406+91 | 1.31 | | Tan | do | | | | |
| 5406+91 | 5412+03 | | .10 | 1° | do | | | | |
| 5412+03 | 5489+88 | 1.47 | | Tan | do | | | | |
| 5489+88 | 5491+60 | | .03 | 50′ | do | | | | |
| 5491+60 | 5495+44 | | .07 | 50′ | | | | | Upper approach. |
| 5495+44 | 5503+37 | .15 | | | | | | 204.5 | Do. |
| 5503+37 | 5509+37 | .11 | | | | 284.09 | | | Lock No. 3. |
| 5509+37 | 5526+69 | .33 | | | | | | 156.8 | Lower approach. |
| 5526+69 | 5531+61 | | .09 | 50′ | | | | | Do. |
| 5531+61 | 5538+93 | | .14 | 50′ | Standard | | | | |
| 5538+93 | 5633 | 1.78 | | Tan | do | | | | |
| 5633 | 5635 | .04 | | | do | 286.47 | 31 02 | | End of Long Sault Canal. |
| 5635 | 7403+31 | 33.49 | | | Open lake | | | | Lake St. Francis. |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

CHAMPLAIN ROUTE—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 7403+31 | 7450+01 | | .88 | 20′ | 600 feet | | | | |
| 7450+01 | 7528+30 | 1.48 | | Tan | do | 322.32 | 34 00 | | |
| 7528+30 | 7550+31 | .42 | | Tan | Standard | | | | |
| 7550+51 | 7561+31 | .21 | | Tan | do | | | | |
| 7561+31 | 7567+42 | .12 | | | | | | 152.4 | Upper approach. |
| 7567+42 | 7573+42 | .11 | | | | 323.18 | | | Lock No. 4 (guard lock). |
| 7573+42 | 7579+32 | .11 | | | | | | 152.4 | Lower approach. |
| 7579+32 | 7685+61 | 2.01 | | Tan | Standard | | | | |
| 7685+61 | 7703+91 | | .35 | 29′ | do | | | | |
| 7703+91 | 7804+91 | 1.91 | | Tan | do | | | | |
| 7804+91 | 7814+21 | | .18 | 34′ | do | | | | |
| 7814+21 | 8113+21 | 5.66 | | Tan | do | | | | Ormstown. |
| 8113+21 | 8163+31 | | .95 | 1° 08′ | do | | | | |
| 8163+31 | 8401+01 | 4.50 | | Tan | do | | | | |
| 8401+01 | 8455+51 | | 1.03 | 34′ | do | | | | |
| 8455+51 | 8631+71 | 3.34 | | Tan | do | | | | |
| 8631+71 | 8649+01 | | .33 | 57′ | do | | | | |
| 8649+01 | 8707+21 | 1.10 | | Tan | do | | | | |
| 8707+21 | 8730+61 | | .44 | 34′ | do | | | | |
| 8730+61 | 8848+36 | 2.23 | | Tan | do | | | | |
| 8848+36 | 8869+51 | | .40 | 49′ | do | | | | |
| 8869+51 | 8931+01 | 1.17 | | Tan | do | | | | |
| 8931+01 | 9006+86 | | 1.44 | 49′ | do | | | | |
| 9006+86 | 9259+61 | 4.79 | | Tan | do | | | | |
| 9259+61 | 9294+41 | | .66 | 49′ | do | | | | |
| 9294+41 | 9332+51 | .72 | | Tan | do | | | | |
| 9332+51 | 9356+91 | | .46 | 57′ | do | | | | |
| 9356+91 | 9368+91 | .23 | | Tan | do | | | | |
| 9368+91 | 9440+11 | | 1.35 | 1° 08′ | do | | | | |
| 9440+11 | 9482+81 | .81 | | Tan | do | | | | |
| 9482+81 | 9520+21 | | .71 | 57′ | do | | | | |
| 9520+21 | 9587+41 | 1.27 | | Tan | do | | | | |
| 9587+41 | 9623+31 | | .68 | 34′ | do | | | | |
| 9623+31 | 9710+11 | 1.64 | | Tan | do | | | | |
| 9710+11 | 9818+81 | | 2.06 | 29′ | do | | | | |
| 9818+81 | 9836+46 | .33 | | Tan | do | | | | |
| 9836+46 | 9869+81 | | .63 | 1° 08′ | do | | | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

CHAMPLAIN ROUTE—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 9869+81 | 9872+30 | .05 | | Tan | Standard | | | | |
| 9872+30 | 9878+37 | .12 | | | | | | 152.4 | Upper approach. |
| 9878+37 | 9884+37 | .11 | | | | 366.95 | | | Lock No. 5. |
| 9884+37 | 9890+31 | .11 | | | | | | 100.0 | Lower approach. |
| 9890+31 | 10024+31 | 2.54 | | Tan | Standard | | | | |
| 10024+31 | 10056+51 | | .61 | 57′ | do | | | | |
| 10056+51 | 10087+31 | .58 | | Tan | do | | | | |
| 10087+31 | 10106+31 | .36 | | Tan | do | 371.15 | 41 34 | | Kings Bay, Lake Champlain. |
| 10106+31 | 10114+91 | .16 | | Tan | 600 feet | | | 100.0 | Lake Champlain. |
| 10114+91 | 10231+31 | | 2.20 | 34′ | do | | | | |
| 10231+31 | Zero | 61.98 | | | Open lake | 435.49 | 46 47 | | Port Henry. |
| 0 | 61+10 | 1.16 | | | do | | | | |
| 61+10 | 101+86 | .77 | | Tan | 600 feet | | | | |
| 101+86 | 146+79 | | .85 | 1° | do | | | | |
| 146+79 | 478+03 | 6.28 | | Tan | do | | | | |
| 478+03 | 531+56 | | 1.02 | 30′ | do | | | | |
| 531+56 | 628+04 | 1.83 | | Tan | do | | | | |
| 628+04 | 678+30 | | .95 | 30′ | do | | | | |
| 678+30 | 788+32 | 2.08 | | Tan | do | | | | |
| 788+32 | 825+32 | | .70 | 1° 16′ | do | | | | |
| 825+32 | 850+86 | .49 | | Tan | do | | | | |
| 850+86 | 922+68 | | 1.36 | 1° | do | | | | |
| 922+68 | 1054+26 | 2.49 | | Tan | do | | | | |
| 1054+26 | 1117+66 | | 1.20 | 50′ | do | | | | |
| 1117+66 | 1201+74 | 1.59 | | Tan | do | | | | |
| 1201+74 | 1236+31 | | .65 | 30′ | do | | | | |
| 1236+31 | 1251+26 | .28 | | Tan | do | | | | |
| 1251+26 | 1255+62 | .08 | | Tan | 470 feet | | | | |
| 1255+62 | 1256+26 | | .01 | 1° | do | | | | |
| 1256+26 | 1298+38 | | .80 | 1° | 450 feet | | | | |
| 1298+38 | 1324+97 | .50 | | Tan | do | | | | |
| 1324+97 | 1365+97 | | .78 | 30′ | do | | | | |
| 1365+97 | 1445+98 | 1.52 | | Tan | do | | | | |
| 1445+98 | 1463+55 | | .33 | 30′ | do | | | | |
| 1463+55 | 1533+97 | 1.33 | | Tan | do | | | | |
| 1533+97 | 1549+99 | | .30 | 1° | do | | | | |
| 1549+99 | 1605+31 | 1.05 | | Tan | do | | | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

CHAMPLAIN ROUTE—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 1605+31 | 1659+41 | | 1.03 | 1° | 450 feet | | | | |
| 1659+41 | 1693+73 | .65 | | Tan | do | | | | |
| 1693+73 | 1734+70 | | .78 | 1° | do | | | | |
| 1734+70 | 1797+92 | 1.20 | | Tan | do | | | | |
| 1797+92 | 1851+26 | | 1.01 | 1° | do | | | | |
| 1851+26 | 1863+90 | .24 | | Tan | do | | | | |
| 1863+90 | 1897+15 | .63 | | Tan | 300 feet | | | | |
| 1897+15 | 1927+80 | | .58 | 1° 16′ | do | | | | |
| 1927+80 | 1956+50 | .54 | | Tan | do | 472.55 | 50 38 | 100.0 | Whitehall. |
| 1956+50 | 1971 | .27 | | Tan | 200 feet | | | | |
| 1971 | 2036+29 | 1.24 | | Tan | Standard | | | | |
| 2036+29 | 2067+06 | | .58 | 30′ | do | | | | |
| 2067+06 | 2262+37 | 3.70 | | Tan | do | | | | |
| 2262+37 | 2286+14 | | .64 | 30′ | do | | | | |
| 2286+14 | 2309+27 | .25 | | Tan | do | | | | |
| 2309+27 | 2330+22 | | .40 | 1° | do | | | | |
| 2330+22 | 2346+09 | .30 | | Tan | do | | | | |
| 2346+09 | 2361+52 | | .29 | 1° | do | | | | |
| 2361+52 | 2371+89 | .20 | | Tan | do | | | | |
| 2371+89 | 2382+42 | | .39 | 1° 16′ | do | | | | |
| 2382+42 | 2389+37 | 1.13 | | Tan | do | | | | |
| 2389+37 | 2439+90 | | .77 | 1° 16′ | do | | | | |
| 2439+90 | 2468+19 | .54 | | Tan | do | | | | |
| 2468+19 | 2487+12 | | .36 | 40′ | do | | | | |
| 2487+12 | 2496+81 | .18 | | Tan | do | | | | |
| 2496+81 | 2553+32 | | 1.07 | 1° 16′ | do | | | | |
| 2553+32 | 2577+43 | .46 | | Tan | do | | | | |
| 2577+43 | 2594+36 | | .32 | 30′ | do | | | | |
| 2594+36 | 2734+34 | 2.65 | | Tan | do | | | | |
| 2734+34 | 2748+81 | | .27 | 30′ | do | | | | |
| 2748+81 | 2789+57 | .77 | | Tan | do | | | | |
| 2789+57 | 2817+19 | | .52 | 1° | do | | | | |
| 2817+19 | 2891+45 | 3.30 | | Tan | do | | | | |
| 2891+45 | 3009+78 | | .35 | 30′ | do | | | | |
| 3009+78 | 3098+81 | 1.69 | | Tan | do | | | | |
| 3098+81 | 3109+92 | .21 | | | | | | 100.0 | Upper approach. |
| 3109+92 | 3115+92 | .11 | | | | 494.51 | | | Lock No. 6 (guard lock). |

*Table of distances, alignment, width of channel, sailing time, and water levels*--Continued.

CHAMPLAIN ROUTE- Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From-- | To-- | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 3115+92 | 3126+82 | .21 | | | | | | 100.0 | Lower approach. |
| 3126+82 | 3142+54 | .30 | | Tan | Standard | | | | |
| 3142+54 | 3153+64 | | .21 | 30′ | do | | | | |
| 3153+64 | 3174+60 | .39 | | Tan | do | 495.62 | 54 05 | | Fort Edward. |
| 3174+60 | 3198+82 | .46 | | Tan | do | | | | |
| 3198+82 | 3241+73 | .81 | | Tan | 300 feet | | | | |
| 3241+73 | 3296+68 | | 1.04 | 1° 16′ | do | | | | |
| 3296+68 | 3320+48 | .45 | | Tan | do | | | | |
| 3320+48 | 3409+51 | | 1.69 | 30′ | do | | | | |
| 3409+51 | 3427+94 | .35 | | Tan | do | | | | |
| 3427+94 | 3449+47 | | .41 | 1° | do | | | | |
| 3449+47 | 3484+07 | .66 | | Tan | do | | | | |
| 3484+07 | 3507+18 | | .44 | 1° 16′ | do | | | | |
| 3507+18 | 3518+46 | .21 | | Tan | do | | | | |
| 3518+46 | 3546+26 | | .53 | 1° | do | | | | |
| 3546+26 | 3589+77 | .82 | | Tan | do | | | | |
| 3589+77 | 3629+74 | | .75 | 1° | do | | | | |
| 3629+74 | 3649+05 | .36 | | Tan | do | | | | |
| 3649+05 | 3704+54 | | 1.05 | 1° 16′ | do | | | | |
| 3704+54 | 3713+36 | .17 | | Tan | do | | | | |
| 3713+36 | 3724+73 | .22 | | | | | | 100.0 | Upper approach. |
| 3724+73 | 3730+73 | .11 | | | | 506.15 | | | Lock No. 7. |
| 3730+73 | 3738+82 | .15 | | | | | | 85.0 | Lower approach. |
| 3738+82 | 3781+61 | .81 | | Tan | 300 feet | | | | |
| 3781+61 | 3833+74 | | .99 | 40′ | do | | | | |
| 3833+74 | 3836+73 | .06 | | Tan | do | | | | |
| 3836+73 | 3860+56 | | .45 | 1° | do | | | | |
| 3860+56 | 3881+68 | .40 | | Tan | do | | | | |
| 3881+68 | 3908+30 | | .50 | 1° 16′ | do | | | | |
| 3908+30 | 3941+43 | | .63 | 1° 16′ | do | | | | |
| 3941+43 | 3964+54 | | .44 | 1° 16′ | do | | | | |
| 3964+54 | 4051+37 | 1.65 | | Tan | do | | | | |
| 4051+37 | 4076+35 | | .47 | 50′ | do | | | | |
| 4076+35 | 4100+11 | .45 | | Tan | do | | | | |
| 4100+11 | 4128+77 | | .54 | 50′ | do | | | | |
| 4128+77 | 4148+54 | .37 | | Tan | do | | | | |
| 4148+54 | 4173+19 | | .47 | 1° 16′ | do | | | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

CHAMPLAIN ROUTE—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From– | To– | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 4173+19 | 4200+41 | | .52 | 1° | 300 feet | | | | |
| 4200+41 | 4221+32 | .40 | | Tan | do | | | | |
| 4221+32 | 4286+32 | 1.23 | | Tan | Standard | | | | |
| 4286+32 | 4303+32 | .32 | | Tan | 300 feet | | | | |
| 4303+32 | 4343+38 | .76 | | Tan | Standard | | | | |
| 4343+38 | 4348+32 | | .09 | 1° | do | | | | |
| 4348+32 | 4362+45 | | .27 | 1° | do | | | | |
| 4362+45 | 4383+72 | .40 | | Tan | 300 feet | | | | |
| 4383+72 | 4439+60 | | 1.06 | 1° | do | | | | |
| 4439+60 | 4457+15 | .33 | | Tan | do | | | | |
| 4457+15 | 4461+82 | | .09 | 30′ | do | | | | |
| 4461+82 | 4472+43 | | .20 | 30′ | Standard | | | | |
| 4472+43 | 4477+81 | .10 | | Tan | do | | | | |
| 4477+81 | 4483+88 | .12 | | | | | | 85.0 | Upper approach. |
| 4483+88 | 4489+88 | .11 | | | | 520.53 | | | Lock No. 8. |
| 4489+88 | 4495+82 | .11 | | | | | | 65.0 | Lower approach. |
| 4495+82 | 4506+32 | .20 | | Tan | Standard | | | | |
| 4506+32 | 4550+10 | .83 | | Tan | 300 feet | | | | |
| 4550+10 | 4565+82 | | .30 | 30′ | do | | | | |
| 4565+82 | 4570+10 | | .08 | 30′ | | | | | Upper approach. |
| 4570+10 | 4581+89 | .23 | | | | | | 65.0 | Do. |
| 4581+89 | 4587+89 | .11 | | | | 522.39 | | | Lock No. 9. |
| 4587+89 | 4603+83 | .30 | | | | | | 48.0 | Lower approach. |
| 4603+83 | 4609+66 | .11 | | Tan | 300 feet | | | | |
| 4609+66 | 4628+53 | | .36 | 1°16′ | do | | | | |
| 4628+53 | 4644+21 | .30 | | Tan | do | | | | |
| 4644+21 | 4669+46 | | .48 | 1° | do | | | | |
| 4669+46 | 4701+82 | .61 | | Tan | do | | | | |
| 4701+82 | 4705+61 | .07 | | Tan | | | | | Upper approach. |
| 4705+61 | 4715+98 | | .19 | 30′ | | | | | Do. |
| 4715+98 | 4717+89 | .04 | | Tan | | | | 48.0 | Do. |
| 4717+89 | 4723+89 | .11 | | | | 524.96 | | | Lock No. 10. |
| 4723+89 | 4736+75 | .24 | | | | | | 30.0 | Lower approach. |
| 4736+75 | 4739+83 | | .06 | 1°16′ | | | | | Do. |
| 4739+83 | 4754+78 | | .28 | 1°16′ | 300 feet | | | | |
| 4754+78 | 4801+07 | .88 | | Tan | do | | | | |
| 4801+07 | 4816+90 | | .30 | 30′ | do | | | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

CHAMPLAIN ROUTE—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 4816+90 | 4843+61 | .51 | | Tan | 300 feet | | | | |
| 4843+61 | 4865+64 | | .42 | 1° | do | | | | |
| 4865+64 | 4874+36 | .16 | | Tan | do | | | | |
| 4874+36 | 4898+66 | | .46 | 1° | do | | | | |
| 4898+66 | 4921+82 | .44 | | Tan | do | | | | |
| 4921+82 | 4929+02 | .14 | | Tan | Standard | | | | |
| 4929+02 | 4966+15 | | .70 | 40′ | do | | | | |
| 4966+15 | 4980+81 | .28 | | Tan | do | | | | |
| 4980+81 | 4996+88 | .31 | | | | | | 30.0 | Upper approach. |
| 4996+88 | 5002+88 | .11 | | | | 530.25 | | | Lock No. 11. |
| 5002+88 | 5009+82 | .13 | | | | | | 15.0 | Lower approach. |
| 5009+82 | 5036+59 | .51 | | Tan | 300 feet | | | | |
| 5036+59 | 5042+56 | | .11 | 30′ | do | | | | |
| 5042+56 | 5121+11 | 1.49 | | Tan | do | | | | |
| 5121+11 | 5137+81 | | .32 | 50′ | do | | | | |
| 5137+81 | 5138+98 | .02 | | Tan | do | | | | |
| 5138+98 | 5162+18 | | .44 | 50′ | do | | | | |
| 5162+18 | 5193+86 | .60 | | Tan | do | | | | |
| 5193+86 | 5195+29 | | .03 | 1°16′ | do | | | | |
| 5195+29 | 5203+82 | | .16 | 1°16′ | | | | | |
| 5203+82 | 5213+06 | .17 | | | | | | | Upper approach. |
| 5213+06 | 5219+06 | .11 | | | | | | 15.0 | Do. |
| 5219+06 | 5226+77 | .15 | | | | 534.34 | | | Lock No. 12. |
| 5226+77 | 5233+30 | | .12 | 1° | | | | 1.2 | Lower approach. |
| 5233+30 | 5243+44 | | .19 | 30′ | 300 feet | 534.80 | 63 25 | | Do. |
| 5243+44 | 5260+10 | .32 | | Tan | do | | | | Troy. |
| 5260+10 | 5275+62 | | .29 | 44′ | do | | | | |
| 5275+62 | 5338+93 | 1.20 | | Tan | do | | | | |
| 5338+93 | 5366+17 | | .52 | 45′ | do | | | | |
| 5366+17 | 5371+39 | .10 | | Tan | do | | | | |
| 5371+39 | 5402+32 | | .59 | 1°16′ | do | | | | |
| 5402+32 | 5454+21 | .98 | | Tan | do | | | | |
| 5454+21 | 5464+18 | | .19 | 38′ | do | | | | |
| 5464+18 | 5508+05 | .83 | | Tan | do | | | | |
| 5508+05 | 5522+34 | | .27 | 49′ | do | | | | |
| 5522+34 | 5540+90 | .35 | | Tan | do | | | | |
| 5540+90 | 5582+56 | .79 | | Tan | 400 feet | | | | |

*Table of distances, alignment, width of channel, sailing time, and water levels*—Continued.

CHAMPLAIN ROUTE—Continued.

[21-foot channel.]

| Stations. | | Distance between stations. | | Degree of curve. | Width of channel. | From Buffalo. | | Elevation of water surface. | Locality. |
|---|---|---|---|---|---|---|---|---|---|
| From— | To— | Tangents. | Curves. | | | Distance. | Time. | | |
| | | *Miles.* | *Miles.* | | | *Miles.* | *Hrs. Min.* | | |
| 5582+56 | 5608+94 | | .50 | 40′ | 400 feet | | | | |
| 5606+94 | 5630+73 | .41 | | Tan | do | | | | Albany. |
| 5630+73 | 5636+36 | | .11 | 38′ | do | | | | |
| 5636+36 | 5742+16 | 2.00 | | Tan | do | | | | |
| 5742+16 | 5757 | | .28 | 38′ | do | 544.53 | 64 38 | 0.2 | Station 5757, mouth of Normans Kill, Hudson River. |
| Buffalo | Hudson River | 472.85 | 71.68 | | | 544.53 | 64 38 | | At mouth of Normans Kill. |
| 5757 | Battery, New York | 131.26 | 9.42 | | | 685.21 | 76 28 | | For details see Oswego-Mohawk route. |
| Buffalo | New York | 604.11 | 81.10 | | | 685.21 | 76 28 | | |

*Estimated cost of excavation and construction.*

21-FOOT CHANNEL.

| | Duluth to tide water. | | Chicago to tide water. | |
|---|---|---|---|---|
| | Lasalle-Lewiston-Champlain route. | Lasalle-Lewiston-Oswego-Mohawk low-level route. | Lasalle-Lewiston-Champlain route. | Lasalle-Lewiston-Oswego-Mohawk low-level route. |
| Excavation | $128,368,611 | $105,100,457 | $123,372,812 | $100,104,638 |
| Retaining walls, slope walls, and back fill | 5,544,621 | 10,822,948 | 5,544,621 | 10,822,948 |
| Embankment | 1,853,154 | 155,014 | 1,853,154 | 155,014 |
| Railroad and highway changes | 707,443 | 1,560,054 | 707,443 | 1,560,054 |
| Right of way | 5,551,765 | 12,478,442 | 5,551,765 | 12,478,442 |
| Bridges and ferries | 4,296,481 | 5,392,010 | 4,296,481 | 5,392,010 |
| By-passes | 43,385 | | 43,385 | |
| Locks | 20,396,732 | 36,328,417 | 20,396,732 | 36,328,417 |
| Cribs at lock approaches | 1,884,702 | 5,629,389 | 1,884,702 | 5,629,389 |
| Lock-operating plant | 1,800,000 | 3,200,000 | 1,800,000 | 3,200,000 |
| Breakwater | | 721,380 | | 721,380 |
| Entrance of streams | 225,096 | 64,371 | 225,096 | 64,371 |
| Dikes | 206,413 | 206,413 | 206,413 | 206,413 |
| Dams | 551,819 | 3,122,610 | 551,819 | 3,122,610 |
| Regulating works | 1,687,167 | 796,923 | 1,687,167 | 796,923 |
| Water supply | | 2,062,295 | | 2,062,295 |
| Buffalo waterworks tunnel | 30,000 | 30,000 | 30,000 | 30,000 |
| | 173,147,389 | 187,670,723 | 168,151,590 | 182,674,924 |
| Engineering, superintendence, and contingencies, 10 per cent *a* | 17,235,047 | 18,687,380 | 16,735,467 | 18,187,800 |
| Total | 190,382,436 | *b* 206,358,103 | 184,887,057 | *c* 200,862,724 |

30-FOOT CHANNEL.

| | | | | |
|---|---|---|---|---|
| Excavation | $231,874,094 | $178,970,590 | $217,601,194 | $164,697,690 |
| Retaining walls, slope walls, and back fill | 7,294,119 | 15,567,970 | 7,294,119 | 15,567,970 |
| Embankment | 1,793,961 | 157,015 | 1,793,961 | 157,015 |
| Railroad and highway changes | 707,443 | 1,560,054 | 707,443 | 1,560,054 |
| Right of way | 5,576,765 | 12,494,442 | 5,551,765 | 12,469,442 |
| Bridges and ferries | 4,635,724 | 5,947,106 | 4,635,724 | 5,947,106 |
| By-passes | 52,115 | | 52,115 | |
| Locks | 32,114,558 | 56,975,392 | 31,191,065 | 56,051,899 |
| Cribs at lock approaches | 2,422,340 | 6,067,266 | 2,004,350 | 5,649,276 |
| Lock-operating plant | 1,900,000 | 3,300,000 | 1,800,000 | 3,200,000 |
| Breakwater | | 1,190,317 | | 1,190,317 |
| Entrance of streams | 225,096 | 64,371 | 225,096 | 64,371 |
| Dikes | 206,413 | 206,413 | 206,413 | 206,413 |
| Dams | 551,819 | 3,122,610 | 551,819 | 3,122,610 |
| Regulating works | 1,687,167 | 796,923 | 1,687,167 | 796,923 |
| Water supply | | 2,062,295 | | 2,062,295 |
| Buffalo waterworks tunnel | 30,000 | 30,000 | 30,000 | 30,000 |
| | 291,071,614 | 288,512,764 | 275,332,231 | 272,773,381 |
| Engineering, superintendence, and contingencies 10 per cent *a* | 29,027,469 | 28,771,584 | 27,453,531 | 27,197,646 |
| Total | 320,099,083 | *b* 317,284,348 | 302,785,762 | *c* 299,971,027 |

*a* Estimate for Lake Erié regulating works already contains cost of engineering, superintendence, and contingencies.
*b* See note, p. 113.
*c* See note, p. 114.

*Estimated cost of divisions.*

LAKES MICHIGAN AND SUPERIOR TO TIDE WATER.

| | 30-foot channel. | 21-foot channel. |
|---|---|---|
| Lake Superior to Lake Erie: | | |
| 1. With regulated surface | $33,539,869 | $6,961,818 |
| 2. Without regulated surface | 41,554,164 | 9,123,923 |
| Lake Michigan to Lake Erie: | | |
| 1. With regulated surface | 16,226,548 | 1,466,439 |
| 2. Without regulated surface | 23,287,911 | 2,979,072 |
| Lake Erie to Lake Ontario: | | |
| Via Lasalle-Lewiston route— | | |
| 1. With regulated surface | 73,435,350 | 42,303,203 |
| 2. Without regulated surface | 75,084,453 | 43,214,344 |
| Via Tonawanda-Olcott route— | | |
| 1. With regulated surface | 75,572,250 | 48,453,753 |
| 2. Without regulated surface | 77,221,353 | 49,274,894 |
| Lake Ontario to tide water: | | |
| Via Oswego-Mohawk route (high-level plan)— | | |
| 1. Western division *a* | 83,395,975 | 65,676,650 |
| 2. Eastern division | 112,474,110 | 85,488,414 |
| 3. Hudson River division | 10,383,468 | 4,159,904 |
| Total *a* | 206,253,553 | 155,324,968 |
| Via Oswego-Mohawk route (low-level plan)— | | |
| 1. Western division *a* | 87,451,551 | 67,354,764 |
| 2. Eastern division | 112,474,110 | 85,488,414 |
| 3. Hudson River division | 10,383,468 | 4,159,904 |
| Total *a* | 210,309,129 | 157,003,082 |
| Via Champlain route (with movable dams)— | | |
| 1. St. Lawrence division | 35,514,438 | 21,027,113 |
| 2. Northern division | 64,008,981 | 47,912,678 |
| 3. Hudson River division, upper | 103,216,977 | 67,927,720 |
| 4. Hudson River division, tidal | 10,383,468 | 4,159,904 |
| Total | 213,123,864 | 141,027,415 |

*Summary of cost of divisions.*

DULUTH TO TIDE WATER.

| | 30-foot channel. | 21-foot channel. |
|---|---|---|
| Via Lasalle-Lewiston (regulated surface): | | |
| Oswego-Mohawk (high-level plan)— | | |
| 1. Lake Superior to Lake Erie | $33,539,869 | $6,961,818 |
| 2. Lake Erie to Lake Ontario | 73,435,350 | 42,303,203 |
| 3. Lake Ontario to tide water *a* | 206,253,553 | 155,324,968 |
| Total *a* | 313,228,772 | 204,679,989 |
| Oswego-Mohawk (low-level plan)— | | |
| 1. Lake Superior to Lake Erie | 33,539,869 | 6,961,818 |
| 2. Lake Erie to Lake Ontario | 73,435,350 | 42,303,203 |
| 3. Lake Ontario to tide water *a* | 210,309,129 | 157,003,082 |
| Total *a* | 317,284,348 | 206,358,103 |
| Champlain (with movable dams)— | | |
| 1. Lake Superior to Lake Erie | 33,539,869 | 6,961,818 |
| 2. Lake Erie to Lake Ontario | 73,435,350 | 42,303,203 |
| 3. Lake Ontario to tide water | 213,123,864 | 141,027,415 |
| Total | 320,099,083 | 190,382,436 |

*a* The estimated cost of the Oswego-Mohawk route is based on the use of swing or bascule bridges at all railroad crossings. If an overhead railroad crossing be adopted for the New York Central Railroad near Utica, with a fixed span over the waterway at a clear height of 85 feet above the water's surface, the estimated cost of the route would be increased $788,000 for the low-level project and $953,000 for the high-level project. With this modification, the total estimated cost of the 21-foot waterway would be $207,146,103 for the low-level project and $205,632,989 for the high-level project. For the 30-foot waterway, the corresponding amounts would be $318,072,348 and $314,181,772.

*Summary of cost of divisions*—Continued.

CHICAGO TO TIDE WATER.

| | 30-foot channel. | 21-foot channel. |
|---|---|---|
| Via Lasalle-Lewiston (regulated surface): | | |
| Oswego-Mohawk (high-level plan)— | | |
| 1. Lake Michigan to Lake Erie | $16,226,548 | $1,466,439 |
| 2. Lake Erie to Lake Ontario | 73,435,350 | 42,393,203 |
| 3. Lake Ontario to tide water *a* | 206,253,553 | 155,324,968 |
| Total *a* | 295,915,451 | 199,184,610 |
| Oswego-Mohawk (low-level plan)— | | |
| 1. Lake Michigan to Lake Erie | 16,226,548 | 1,466,439 |
| 2. Lake Erie to Lake Ontario | 73,435,350 | 42,393,203 |
| 3. Lake Ontario to tide water *a* | 210,309,129 | 157,003,082 |
| Total *a* | 299,971,027 | 200,862,724 |
| Champlain (with movable dams)— | | |
| 1. Lake Michigan to Lake Erie | 16,226,548 | 1,466,439 |
| 2. Lake Erie to Lake Ontario | 73,435,350 | 42,393,203 |
| 3. Lake Ontario to tide water | 213,123,864 | 141,027,415 |
| Total | 302,785,762 | 184,887,057 |

*a* The estimated cost of the Oswego-Mohawk route is based on the use of swing or bascule bridges at all railroad crossings. If an overhead railroad crossing be adopted for the New York Central Railroad near Utica, with a fixed span over the waterway at a clear height of 85 feet above the water's surface, the estimated cost of the route would be increased $788,000 for the low-level project and $953,000 for the high-level project. With this modification, the total estimated cost of the 21-foot waterway would be $201,650,724 for the low-level project and $200,137,610 for the high-level project. For the 30-foot waterway the corresponding amounts would be $300,759,027 and $296,868,451.

## THE RELATIVE ADVANTAGES OF THE 21 AND 30 FOOT WATERWAYS.

In the preceding divisions of this report the various routes surveyed and investigated by the Board for waterways of different depths from the Great Lakes to the Atlantic tide waters have been described and discussed from a physical point of view and estimates of their cost of construction have been given. The Board now submits a statement of the relative advantages of the 21 and 30 foot waterways, as required by the provisions of the sundry civil act of July 1, 1898.

The benefits to be derived from a waterway from the lakes to the seaboard result directly from low rates and ample facilities for the transportation of freight between the terminals and from the development of new industries and new commerce. At the commencement of the investigation of this subject an effort was made to collect statistics showing the effect of better transportation facilities on the commerce of the country, with especial reference to determining whether the indirect benefits to the producers of the country would justify large expenditures in the increase of transportation facilities in excess of the actual requirements for the lake traffic. It was found, however, that a satisfactory solution of this problem would require more time and money than was at the disposal of the Board, and that the results, when obtained, would not be sufficiently conclusive to warrant making them a basis for estimates. Statistics of lake and ocean commerce are collected, arranged, and discussed in the publications of the Bureau of Statistics of the Treasury Department, and from these publications all the information can be obtained which can be

employed to advantage in the investigation of the problem of relative advantages submitted by Congress to the Board. This problem is of a speculative character, since it involves the consideration of conditions which will exist after a deep waterway has been established—conditions which will be very different from those existing at the present time. The Board therefore considers it useless to seek for great accuracy and detail in the statement of existing commercial conditions.

An exhaustive study of the relative advantages of routes of different depths has been made by Lieut. Col. C. W. Raymond, member of the Board (Appendix No. 5), from which it appears that the benefits to be derived from the respective waterways are so well defined that further statistical inquiry would add but little to the force of the conclusions. This investigation was made by Colonel Raymond in consultation with the other members of the Board, and his report fully expresses their views on this subject. The details of the investigation are given in Appendix No. 5. In this report it is only necessary to give an outline of the method of investigation followed, and a summary of the conclusions at which the Board has arrived.

A waterway connecting the Great Lakes with the sea may be regarded as an instrument of commerce for the purpose of increasing the value of merchandise by transporting it from one point to another. Waterways of different dimensions and cost may be compared from this point of view, and their relative direct advantages as compared with each other, and with the amounts required for their construction may be approximately determined. Such comparisons, however, are too narrow and limited for a satisfactory solution of the question of relative advantages. Indirect benefits may result from the establishment of a great transportation line, which may be of such importance in their influence upon production, commerce, and the general prosperity of the people that the question of a greater or less return of direct value may become comparatively insignificant. Accordingly, the investigation of the question of relative advantages has been considered under two heads, viz, relative direct advantages, and relative indirect advantages.

In determining the relative direct advantages of the waterways compared, an attempt has been made to express the relations existing between the various elements entering the problem in a mathematical formula from which may be obtained numerical quantities representing approximately the relative values of the waterways considered. These elements are the traffic capacities of the waterways, the costs of construction and maintenance, and the cost of transport proper in the most economical type-carriers. The board believes this method of stating and discussing the problem has the great advantage of exhibiting clearly the elements upon which it depends and the uncertainties unavoidable in such investigations.

The determination of relative direct benefit has been limited to the consideration of through traffic conducted in the most economical carriers. The waterways extend from Duluth to New York and from Chicago to New York. For each route these lines of through traffic are considered separately, both for foreign and domestic traffic.

The routes from Duluth and Chicago to New York which are compared are as follows:

1. Thirty-foot waterway via La Salle, Lewiston, St. Lawrence River, and Lake Champlain.
2. Thirty-foot waterway via La Salle, Lewiston, and the Mohawk Valley, high-level plan.
3. Thirty-foot waterway via La Salle, Lewiston, and the Mohawk Valley, low-level plan.
4. Twenty-one-foot waterway via La Salle, Lewiston, St. Lawrence River, and Lake Champlain.
5. Twenty-one-foot waterway via Lasalle, Lewiston, and the Mohawk Valley, high-level plan.
6. Twenty-one-foot waterway via Lasalle, Lewiston, and the Mohawk Valley, low-level plan.

The traffic is supposed to consist of the movement of bulky freight, such as grain, coal, lumber, and ores, to domestic and coast markets or to markets beyond the sea. For each depth of waterway a type carrier is adopted which is believed to furnish the most economical transportation. The data for the comparisons are determined principally from the estimates of the Board.

The formula gives for each waterway a measure of its relative annual return of value upon each $100 expended in construction, after the payment of the costs of maintenance, operation, and transport proper, as compared with a standard waterway for which the return of value is assumed as unity.

The results obtained by this method of investigation are briefly as follows:

1. The return of direct benefit from the 30-foot waterway via the St. Lawrence River and Lake Champlain is less for both foreign and domestic traffic than the return from either of the Mohawk Valley routes. The two Mohawk Valley waterways give practically the same returns.
2. All the 21-foot waterways give practically the same return of direct benefit.
3. The return of direct benefit from the 21-foot waterway is much greater than the return from the 30-foot waterway.

In order to form an estimate of the relative indirect advantages of the waterways compared it was found necessary to consider the amount and character of the existing lake traffic and its past and probable future development, to point out the distinguishing peculiarities of transportation lines of different character and capacity, and to indi-

cate the objects which the proposed waterways are intended to subserve. The following condensed discussion of these subjects is taken from Appendix No. 5.

THE LAKE TRAFFIC.

The demand for increased facilities and diminished rates of transportation from the region of the Great Lakes to the interior of the country and to the sea is based upon facts which are believed to be established by the history of the development of the productive resources of this part of our territory. The commodities forming the bulk of the traffic for which provision is desired are grain (including flour), iron ore, lumber, coal, and manufactured products.

The movement of the four leading commodities above mentioned comprises about 90 per cent of the total freight movement on the lakes. As will be shown hereafter, the greater part of this traffic goes to the domestic markets of our country, but still an important part is destined to foreign markets. The volume of these products has increased rapidly with every increase in the facilities of transportation and with every permanent decrease in transportation rates. It is claimed that further increase in facilities and reduction in rates is absolutely necessary if we would hold our place in foreign markets in competition with the products of other countries.

The following table[1] shows for the year 1898 the traffic for each of the four leading commodities referred to above, the eastward traffic (that is, the traffic east of Detroit), and the quantities destined to domestic and foreign markets, respectively:

| Commodity. | Total traffic. | Eastward traffic. | | |
|---|---|---|---|---|
| | | Total. | Domestic. | Export. |
| | *Net tons.* | *Net tons.* | *Net tons.* | *Net tons.* |
| Grain (including flour) | 12,036,013 | 12,036,013 | 2,888,829 | *a* 9,147,184 |
| Iron ores | 13,650,788 | 11,028,321 | 11,028,321 | ..... |
| Lumber | 4,540,000 | 2,531,180 | 2,531,180 | ..... |
| Coal | 8,722,667 | ..... | ..... | ..... |
| Total | 38,949,468 | 25,595,514 | 16,448,330 | 9,147,184 |

*a* Exports from Montreal, Boston, New York, Philadelphia, and Baltimore.

To indicate the magnitude of the past development of this commerce, it is only necessary to say that the total lake traffic for the year 1871 has been estimated at 14,283,000 tons. Since that time transportation facilities by rail and water have been greatly increased, new locks around the falls of St. Marys River have been constructed, the Welland Canal has been deepened, the lake harbors and channels have been improved, steam vessels have taken the place of sailing

[1] The figures for grain (including flour) are compiled from a report entitled "The Grain Trade of the United States," published by the Bureau of Statistics of the Treasury Department, January, 1900. The other figures are based upon data obtained from the admirable tables which accompany the report of the committee on canals of New York State, 1899.

vessels, and the population of the country has about doubled. These are the principal causes of this enormous expansion of the volume of traffic.

### FUTURE DEVELOPMENT OF LAKE TRAFFIC.

The population of the country will surely continue to increase rapidly, and this must be accompanied by an increase in the volume of the lake traffic. It must not, however, be inferred that the eastward traffic will develop in direct proportion to the increase in population of the country, for about one-half of our population is situated in the great Mississippi basin, where the rate of increase is much greater than in our Eastern territory. The future demands of this part of our country upon the products of the lake region will doubtless reduce the relative amount of Eastern traffic. Nevertheless it does not seem unreasonable to believe that the ratio of demand to supply will continue to be as great as it is at the present time even should the facilities for transportation be very largely increased.

It appears from the table given above that only about one-third of the eastbound lake freight is exported to foreign countries, the remainder being distributed to domestic markets. Practically the entire exports of commodities transported on the lakes and received from the lake region consists of grain and other food products.

### GRAIN.

As regards the future development of the production of grain in the region tributary to the lakes, it is only necessary to point out that the rapid increase of our population will imperatively demand the utilization of all our food-producing areas in the near future for the supply of our own markets. It has been stated by Hon. John Hyde, Chief Statistician of the Agricultural Department, that within the short period of thirty years more than the entire wheat production of the country will be required for consumption by our own people, to the entire exclusion of our export trade.[1] Even should this view not be accepted by all, it must be admitted that the ratio of the export trade to the domestic trade in food products must rapidly diminish.

### IRON ORE.

The movement of iron ore, which forms at the present time so large a proportion of the lake traffic, is principally from Lake Superior to Lake Erie ports, from which the ore is sent by rail to the great coal and iron region of which Pittsburg is the center. As the undeveloped resources of the Lake Superior region are enormous, this traffic may increase greatly under the demands resulting from increased population. Should adequate facilities for water transportation be provided,

[1] "America and the wheat problem." Published in The Wheat Problem, by Sir William Crookes, F. R. S.

it is possible that a considerable part of these products may be carried to points within the interior of the State of New York, where convenient limestone and the saving in cost of transportation both of the crude material and finished product, may compensate for the advantage of the Pittsburg district in its greater proximity to coke and coal.[1] None of this ore is exported at the present time, nor is it probable that much of it ever will be except in the form of finished material.

LUMBER.

Of the four leading commodities considered, lumber forms the smallest proportion of the lake traffic, and its movement is rapidly diminishing. The reasons for this rapid decrease are fully and clearly stated by Prof. George G. Tunnell in his able report on lake commerce.[2] It is largely due to the destruction of the forests on the shores of the lakes and on the banks of the tributary streams. Lumber is now principally obtained at points so far in the interior that it is generally cheaper to saw logs at local mills and transport the product by rail than to carry or float them to the water and transship them. Moreover, there is a strong and increasing competition in Northern markets from Southern lumber. The exports of lumber from the lake region are now insignificant, and they must cease in the near future, as much more than our entire product will soon be needed for our own people.

COAL.

The total volume of eastward traffic on the lakes greatly exceeds that of the westward traffic. The lake movement of coal, which is entirely westward, is therefore of great importance, not only because it supplies the necessities of the territory west and north of Lakes Michigan and Superior, but also because it furnishes a return freight for the lake carriers. Professor Tunnell states that during 1896 coal constituted about three-fourths of the westbound traffic through the Detroit River and 86 per cent of the westbound traffic through the St. Marys Falls Canal.

Most of this material is shipped from the ports of Lake Erie to Duluth and Superior, at the head of Lake Superior, and to Chicago and Milwaukee, at the head of Lake Michigan, the shipments to Lake Superior being much greater than those to Lake Michigan, as in the latter case the conditions are more favorable for railway competition.

At the present time none of the coal transported on the lakes is sent to markets beyond sea, but if a deep waterway to the seacoast were constructed it would probably become an important factor in our export traffic.

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[1] Report of Committee on Canals of New York State, 1899, p. 15.

[2] Document No. 277, House of Representatives, Fifty-fifth Congress, second session.

SUMMARY.

To summarize the above statements, the freight traffic of the Great Lakes, already amounting to at least 40,000,000 tons per year,[1] may be expected to increase greatly and rapidly with increase of population and the extension and cheapening of facilities for transportation, but this traffic will tend more and more to domestic markets and less and less to foreign ones.

CHARACTERISTICS OF TRANSPORTATION LINES.

These conditions appear to fully justify the establishment of new facilities for transportation from the lakes to the sea either by the General Government or by State or private enterprise. At the present time by far the greater part of the traffic between lake and ocean is by railway, only about one twenty-fifth of the volume transported going by canal and river. If a new line for water transportation is to be established it must be done by the General or State governments, not only on account of the great expenditure involved, but also because such a line is not so desirable for private ownership and operation as a railway upon which the carrier business can be monopolized by the owner, and therefore it probably would not be constructed by private enterprise. In order that the consequences involved in the proposed change of the greater part of the traffic from rail to water transportation may be clearly understood, the principal characteristics of railways and waterways considered as instruments of commerce for the transportation of freight must now be pointed out.

It is frequently asserted that water transportation is always much cheaper than transportation by rail; but this statement can not be accepted without qualification. If it is intended to mean that the cost of transport proper is generally less in the case of the waterway than in the case of the railway, the statement is doubtless true; but if the toll is included in the cost of transport for the waterway as well as for the railway, the cost of transportation will be often less for the railway than for the waterway, when the latter is an artificial channel of moderate dimensions.

As a line of communication between the same terminals, the railway is, for obvious reasons, almost always shorter than the water line. Moreover, it carries passengers, and a considerable part of its freight is of large value in proportion to its bulk. The passengers and high-class freight are made to bear a large proportion of the mean cost of transportation. A distinguished authority[2] on this subject finds from

[1] The registered tonnage of the lake traffic for 1898, as given in the report of the New York State committee on canals, is 62,023,000. A large percentage of this is the registered tonnage of passenger steamers.

[2] C. Colson, Ingénieur des Ponts et Chaussées, Maitre des Requêtes au Conseil d'Etat. Transports et Tarifs, Paris, 1890.

a study of experience on French railways and waterways that between two given points the mean net cost of transportation by rail is generally lower than the cost of transportation by water; but it must be remembered that the canals of France are of small dimensions and not well adapted to economical traffic. In short, no general rule on this subject can be laid down. Each case must be separately investigated and the relative economical advantages of the rail and waterway must be determined in accordance with the existing special conditions. Even then it is not easy to make a satisfactory comparison, owing to characteristic differences in the methods of conducting transportation by the two lines. Generally the railroad carries passengers and a great variety of high-class as well as low-class freight, so that it is exceedingly difficult to determine the average cost of transportation of any assumed freight unit.

One of the most important differences between the railway and the waterway arises from the fact that in the case of the former the proprietor of the line and depots for receiving and shipping freight and the carrier are one and the same party, while in the case of the latter these interests are generally in different hands. It results from this that railway service is much more regular and efficient than water service, because it is under a centralized management.

The skill and efficiency with which the railway service is managed and improved and the lack of improvement and efficient management in canal transportation have often been pointed out, but it does not seem to have been observed that these differences are largely inherent in the different character of the organizations of the two services. The management of the railway is as much interested in the shipping, receiving, and movement of the traffic as in the toll, while in the case of the waterway each interest is concerned with the others only so far as may appear to be for its own direct benefit.

In the case of waterways of small dimensions delays are more liable to occur from accidents and crowding than in the case of the railway. The railway, when compared with the small waterway, has generally the great advantage of speed, which secures for it all the traffic in which time of transport is an element of importance.

Finally, the railway is available for traffic during the whole year, while the waterway must be closed during the season of ice.

M. Colson remarks that experience shows that generally these advantages of the railway cause it to be preferred for merchandise of moderate value when the rates do not exceed those of water transportation by more than 20 per cent.[1] This deduction, however, is doubtless based upon a study of the traffic upon the railways and small canals of France.

The net cost of transportation upon the waterways herein considered, for both domestic and foreign traffic, would of course be very

[1] Tarifs et Transports, p. 310.

much smaller than on a railway or combined lake and railway line, even should the toll be included. Moreover, it is important that the facilities provided for increased traffic movement should be fully adequate to meet all possible future demands, and the waterways have a traffic capacity exceeding that which could be furnished by railways at the same cost. The total freight tonnage of the New York Central and Hudson River Railroad in 1898 was 23,403,439 tons, which is much less than the maximum traffic capacity of the 21-foot waterway.

An important advantage of the waterway over the railway results from the characteristic feature of its organization which has been already pointed out—that the various interests of line manager, freight shipper and receiver, and carrier are in different and independent hands. The maximum amount of benefit is derived from the traffic by the users of the line (or general public) when the toll and transport proper are made as small as possible. In the case of a railway, where the entire system is controlled by a single management, the natural effort is to obtain for the proprietor and carrier as much as possible of the value derived from the traffic—in other words, to make the traffic pay what it will bear. In the case of a large waterway open to the use of all carriers, the element of free competition regulates the rate of transport proper, and under the circumstances the charge for transportation must tend to approximate the net cost.

But it is not merely from the reduction of rates that benefit is derived. One of the most injurious effects of the lack of free competition in railway traffic has been the variation of rates through a wide range, resulting from alternate competition and combination of transportation lines. It has been found difficult, if not impossible, to control these variations by law, but the influence of a large waterway, open to the use of all carriers, could not fail to prevent large fluctuations in railway charges upon bulky freight during the season of its operation.

It has already been pointed out that this characteristic feature of waterways is a disadvantage so far as regards regularity of service and efficiency of management, and this is one reason why it may be considered desirable for the Government to own and manage the waterway and assume the toll. Under these circumstances the public will receive all the benefit derived from the traffic, after the carrier has been paid his charges, and these charges will be kept from large fluctuation and near the net cost of transport by the action of free competition. It would, at first sight, seem unfair for the Government to assume the toll on one transportation line to enable it to compete to advantage with other lines constructed and operated by its own citizens, but it is claimed that the increased demand for a higher class of freight created by the business and prosperity which would inevitably follow the construction of a great waterway would more than compensate the railways for the loss of the low-class traffic. It

would not be to the public interest to have the high-class traffic diverted from the railways to the waterways, but high-class freight is package freight, not readily handled by mechanical devices, and therefore not likely to go by water.

This characteristic feature of water transportation controls not only the movement of the freight, but also its shipment and delivery. In the case of the railway, stations are established at which freight must be handled under the direction of the management. In the case of the waterway, every point upon its banks is a possible station. The result must be an active competition, which must control and cheapen the cost of handling and develop points of shipment and delivery best suited to economical receipt and distribution.

It is claimed as a great advantage of waterways of sufficient dimensions for navigation by ships that they permit of the transport of the cargo through to domestic or foreign ports without transfer from one carrier to another, thus saving the time and cost of handling and loss by waste. This is an advantage of the ship canal as compared with the barge canal of moderate dimensions as well as with the railway. It is, however, considered by high authorities very doubtful whether a vessel can be so constructed as to navigate successfully and economically the ocean, the lakes, and the canal. The ocean vessel must be stronger than the lake vessel and more costly in construction, operation, and maintenance, and it must be fitted with expensive appliances which are not required in the lake traffic. In considering this question, it must be remembered that under existing conditions the lake vessel is compelled to be idle during about one-third of the year, while if it had free access to the sea and were constructed for foreign or coast navigation, it could be earning money all the year round.

Mr. Kirby estimates the cost of our type vessel No. 1 (see Appendix No. 5), when designed for lake and ocean business, at $387,000, and when designed for lake business only, at $360,000. The daily cost of maintenance and operation, including 5 per cent on first cost, is in the first case $331, and in the second $404. Such a vessel, when designed for lake and ocean business, could carry a full cargo from Duluth or Chicago to New York, and, owing to the additional buoyancy of sea water, then take on all the coal required for the ocean voyage without overloading.

The benefit to commerce which would result from giving access to shipping from the lakes to the sea, thus rescuing the lake fleet from enforced idleness during one-third of the year, would, of course, be enormous, if the problem of constructing a vessel economically adapted to both kinds of service can be satisfactorily solved. This is a benefit which is peculiar to the waterway and can not be derived from the extension of railway facilities.

It is further stated that if adequate water communication with the sea were provided, a great industry in the construction of steel ships

would be immediately developed on the lakes. This industry is already an important one, no less than 1,258 vessels having been constructed at the lake ports during the last ten years; but as there is no access to the sea for vessels of more than about 13 feet draft, the business is almost exclusively confined to the construction of ships for the Lake service.

It is claimed that nowhere in the world are the conditions for the economical construction of steel vessels more favorable than at some of the lake ports. Cleveland, for example, is the center of a great iron and steel manufacture. It is farther from the coke-producing district than Pittsburg, but this disadvantage is counterbalanced by its advantage of receiving ores by direct and cheap water transportation. The opening of a deep waterway to the sea would enable the shipyards of the lakes to compete with those of the seacoast in the construction of vessels for the ocean traffic.

Finally, the argument has often been advanced that a deep waterway connecting the lakes with the sea would be of great military value in connection with the defense of the northern frontier of the country. Such a waterway would enable ships of war to pass between the sea and the lakes, and it would also permit the economical construction of such vessels at the lake shipyards.

The preceding brief statement of commercial and transportation conditions and of the benefits which may be expected to result from the establishment of a deep waterway from the lakes to the sea is intended only as a basis for the comparison of the relative advantages and disadvantages of the 21-foot and 30-foot waterways. Under the provisions of law it is not the duty of the Board to report upon the general question as to whether the requirements of commerce justify the construction of a deep waterway at the expense of the General Government, or to compare the advantages of such a waterway with those of one with moderate dimensions requiring transfers of freight at both its terminals. Nevertheless, before making the comparison required by law, it seems desirable to invite attention to two important points.

The first point is that if any project is undertaken by the Government it should be fully adequate to the present and future purposes which it is intended to subserve. It has been remarked by a distinguished authority that the life of any public work is practically coincident with that of the generation which began it. This is especially true in a country like our own, where population increases and commerce develops with amazing rapidity. The reason why it is true is because, in the construction of such works, future necessities are almost invariably underestimated. For example, the first canal and locks at St. Marys Falls were completed in 1855 at a cost of about $1,000,000. To meet the necessities of the increasing traffic, a new and much larger lock and canal were commenced in 1870 and completed in 1881 at a cost of $2,171,000, including canal enlargement. This was

soon found to be insufficient for the requirements of the lake navigation, and still another and larger lock was commenced in 1887 and completed in 1896 at a cost of about $3,700,000, including also canal enlargement. The volume of the lake traffic has so greatly increased that at the present time the construction of a new lock is under consideration. In 1870, no one could have been bold enough to suggest the construction of a lock of the size and cost of the Poe lock recently completed; and yet, if such a lock had been then constructed, the results would have been a large saving to the Government and a great benefit to the commercial interests of the Lakes.

It is therefore of the highest importance that any waterway constructed by the Government should be fully capable of meeting every possible commercial demand which may arise in the future. A lack of capacity for future commerce might necessitate its entire reconstruction at enormous cost, and require an adaptation of vessels and traffic to new conditions involving great loss to commercial interests.

The second point is that any project undertaken by the Government should be of a national and not of a local character, benefiting many and varied commercial interests and exerting its influence over as great an extent of the country as possible. It is easily conceivable that a barge canal of moderate dimensions, requiring transfers at Buffalo and New York, might be of more direct benefit to the State of New York than a canal of sufficient dimensions for the uninterrupted passage of ships; but much of this benefit would be at the expense of the producers and shippers of other parts of the country. Moreover, with such a canal the large interests of shipbuilding and winter traffic for the lake fleet would be unprovided for.

It appears from the investigations of the Board that the most favorable route for a 30-foot waterway from the Lakes to the sea is from Lake Erie to Lake Ontario via Lasalle and Lewiston, and from Lake Ontario to the Hudson River via Oswego and the Mohawk Valley, on the low level plan, and that the same route is practically as favorable as any for the 21-foot waterway. This route is entirely in our own country and has a longer season of navigation than the more northerly line. The problem of its defense is, of course, much simpler than it would be were a part of it in a foreign country, and it is available as a line of communication for ships of war. In the following comparison of the 21-foot and 30-foot waterways, this route will alone be considered.

## COST OF CONSTRUCTION.

The estimated cost of the 21-foot waterway on the low-level plan is $206,358,000; the estimated cost of the 30-foot waterway is $317,284,500, to which should be added about $9,607,500 for the necessary deepening of the harbors at Duluth and Chicago, making the total cost $326,892,000.

### COST OF MAINTENANCE AND OPERATION.

The annual cost of maintenance and operation is estimated at $2,343,478 for the 21-foot waterway, and $2,930,308 for the 30-foot waterway.

### COST OF TRANSPORT PROPER.

The theoretical cost of moving the freight unit, exclusive of toll, from one terminal to the other on the lines considered, is given in the following table:

| Route, New York to— | 21-foot waterway. | | | | 30-foot waterway. | | | |
|---|---|---|---|---|---|---|---|---|
| | Domestic. | | Foreign. | | Domestic. | | Foreign. | |
| | Total cost. | Cost per ton mile. | Total cost. | Cost per ton-mile. | Total cost. | Cost per ton-mile. | Total cost. | Cost per ton-mile. |
| | *Cents.* | *Mills.* | *Cents.* | *Mills.* | *Cents.* | *Mills.* | *Cents.* | *Mills.* |
| Duluth | 45.2 | 0.31 | 70.2 | 0.48 | 45.4 | 0.31 | 40.9 | 0.28 |
| Chicago | 42.3 | .31 | 67.3 | .49 | 42.7 | .31 | 38.2 | .28 |
| Mean | | .310 | | .485 | | .310 | | .280 |

It must be remembered that these values are purely theoretical, and are not given as the probable freight rates; but they are believed to be proportional to the latter, and may, therefore, be taken as relative measures of the cost of transport proper for the waterways compared.

The table shows that the cost of transport proper on the 21-foot waterway is about the same for domestic traffic as on the 30-foot waterway. For foreign traffic the 30-foot waterway shows a much lower cost of transport than the 21-foot waterway.

### TRAFFIC CAPACITY.

The maximum annual traffic capacity of the 21-foot waterway (when the single-lift locks are duplicated) is estimated at 36,608,000 net tons, and that of the 30-foot waterway at 35,180,000 net tons, the traffic on the smaller waterway being greater than that on the larger one, owing to difference in time expended in lockage. It should, however, be remarked that with smaller locks properly proportioned for the most economical type carrier the traffic capacity of the larger waterway would be somewhat increased.

### SPEED.

The average speed on the 21-foot waterway is 10.67 miles per hour. The average speed on the 30-foot waterway is 10 miles per hour.

### ADAPTABILITY TO TRAFFIC CONDITIONS.

Our vessel No. 1, which is the type vessel adopted for the 21-foot waterway, has a draft of 19 feet and can enter all the important lake

harbors as well as navigate along the seacoast. It is, therefore, much better adapted to domestic traffic than vessel No. 2, the type vessel for the 30-foot waterway, since the latter has a draft of 27 feet and can not enter the lake harbors. The smaller vessel is not so well adapted to deep-sea navigation as the larger one.

### REGULARITY OF SERVICE.

In the 30-foot waterway navigation would be freer and for smaller vessels a little more rapid than in the 21-foot waterway, and there would be less danger of delay from accidents and crowding. The time required for vessel No. 1 to make a single trip from Duluth to New York on the 30-foot waterway is six days and three hours, while the same journey on the 21-foot waterway would require two hours longer.

### INFLUENCE ON RAILWAY RATES.

As both waterways furnish low rates for large traffic volumes, there seems to be little choice between them in this respect.

### OUTLET FOR THE LAKE FLEET.

Even should a 30-foot waterway be established between the lakes and the sea, it is probable that the number of vessels of large draft in the lake service would be comparatively small, since such vessels could not enter most of the lake harbors and would be adapted only to through and principally foreign traffic. The 21-foot waterway would, therefore, be practically as good as the 30-foot waterway as a means of access to the sea for the lake fleet.

### ROUTE FOR SHIPS OF WAR.

In the very improbable event of a war with Great Britain every large ship of war possessed by this country would be required on the high sea. Such vessels would be unnecessary on the lakes, since the greatest depth of the Canadian waterways is only 14 feet. For purposes of naval defense the 21-foot waterway appears to offer ample facilities.

### SHIPBUILDING.

The 30-foot waterway would enable the shipbuilders of the lakes to construct seagoing vessels of the largest size, both for commercial and naval purposes. With the 21-foot waterway this industry must be restricted to the construction of vessels of not too great dimensions to pass the locks. If the width of the locks were made greater than is necessary for the type carrier, ships of larger size could be floated from the lake shipyards to the seaboard when light. This would increase the cost of the canal and diminish its traffic capacity.

## CONCLUSION.

As the result of this investigation, it appears that the 21-foot waterway promises a much greater return of value relatively to its cost than the 30-foot waterway. The main advantages of the 30-foot waterway are that it would furnish the lowest cost of transport proper to foreign markets and permit the construction of the largest seagoing vessels on the lakes.

The Board desires to express its obligations and thanks to the Canadian government for permitting surveys to be made within Canadian territory, and to the Montreal harbor commission for facilities extended for examining the Canadian canals. Thanks are due to many Canadian engineers for their cordial cooperation and assistance. Among these, the Board is especially indebted to Messrs. Thomas C. Kiefer, John Kennedy, Ernst Marceau, Thomas Monro, T. S. Rubidge, and J. G. Macklin for courtesies and valuable information.

The Board desires to express its sincere thanks to Brig. Gen. John M. Wilson, Chief of Engineers, United States Army, and to the officers of the Engineer Department in Washington, for their courteous assistance during the entire progress of the work. Its thanks are also due to Lieut. Col. G. J. Lydecker, Corps of Engineers; Mr. Joseph Ripley, superintendent of the St. Marys Falls Canal; Professors E. A. Fuertes and G. S. Williams, of Cornell University; Mr. Frank E. Kirby and Mr. Edwin S. Cramp, marine engineers; the Detroit Bridge and Iron Works, and the United States Coast and Geological Surveys.

The Board wishes to express its high appreciation of the ability, faithfulness, and efficiency of its secretary and of the assistant engineers in charge of the various divisions of the work, whose reports are appended hereto. Special mention should be made of Mr. James H. Brace, who has efficiently filled the important position of principal assistant engineer during the preparation of this report, since his name does not appear elsewhere as in charge of responsible work.

Respectfully submitted.

C. W. RAYMOND,
*Lieutenant-Colonel, Corps of Engineers.*
ALFRED NOBLE.
GEO. Y. WISNER.

Hon. ELIHU ROOT,
*Secretary of War.*

# APPENDIXES

## APPENDIX NO. 1.

### LOCKS.

One of the most strongly marked features of recent navigation, both on the ocean and the Great Lakes, has been the steady increase in size of ships. The most accessible record relating to the Great Lakes is that of the St. Marys Falls Canal. During the year ending June 30, 1882, there were 4,384 passages by registered vessels, with a total net registered tonnage for the year of 2,379,216, or an average of 543 tons per passage. During the calendar year of 1891 the average was 862 tons per passage; in 1899 the average was 1,146 tons, an increase of more than 100 per cent in seventeen years.

Although these figures show the rate of increase in registered tonnage, they do not give an accurate idea of the character of that change. While it has been on the whole a continuous increase, it has been greatest when large additions were made to the navigable depth of water in the principal lake harbors and in the channels connecting the lakes. In 1870 freight through the canal was carried mainly in sailing vessels of 300 to 400 tons net register, carrying cargoes of 600 to 700 tons on 11 to 12 feet of water, which was then the limiting depth. During the next eleven years the deepening of the harbors and connecting channels to 16 feet at meau stage was in progress, but was not available until the opening of the Weitzel lock, in 1881. This period was marked by the introduction of freight steamships, each towing one to three sailing barges. The net register of these ships was in most cases less than 1,000 tons, but a few were built of about 1,500 tons. In anticipation of the opening of deeper waterways, the new ships were designed to draw 14 to 15 feet when fully loaded.

With the opening of the Weitzel lock the building of small sailing ships was checked, and after four or five years ceased almost entirely. The old ships became comparatively unprofitable, and during seasons of low freight rates many were put out of commission. The building of a larger class of ships of from 800 to 1,700 tons net register was taken up, and they carried a constantly increasing proportion of freight.

The Canadian lock was opened in 1895 and the Poe lock in 1896, with a depth of 20 to 21 feet on the sills. As in the case of the Weit-

zel lock, the increased draft had been to some extent anticipated by the building of ships which could not be fully loaded on a draft of 16 feet. Several exceeded 2,000 tons net register, and a few exceeded 2,500. These ships were designed to carry about twice the register, but up to the end of 1894 the maximum cargo was less than 3,800 tons, showing that the depth of water in the channels did not permit full loading. The season of 1895, when the Canadian lock was opened, happened to be one of low water. Several large ships of nearly 3,000 tons register were in commission and two which exceeded 3,300, but the maximum cargo was only 4,400 net tons. During the next two years there was little increase in size, but about thirty ships were built which slightly exceeded 3,000 tons net register. With improved conditions in the harbors and channels, the maximum cargo rose to 6,244 net tons. In 1898 three ships of more than 4,000 tons register were in service, and the maximum cargo was 7,840 net tons. The maximum cargo in 1899, 8,339 tons, was carried by the *John Smeaton*, which has a registered tonnage of 4,725.

The economy of transportation in these large ships has been so marked that the building of ships of less net registered tonnage than 2,000 for the through freight business from Lake Superior to Lake Erie ports has practically ceased. The largest ships now in use on the lakes have a length of 500 feet over all and a beam of about 52 feet. It is hazardous to say that the limit of dimensions has been reached or neared, but when it is considered how rapidly the cost of a ship increases with its length and how difficult it is to secure structural strength without increase of draft, it seems reasonable to conclude that no further very marked increase will take place until the harbors and connecting channels are made deeper.

Although the existing channels do not have quite 21 feet of water, the larger ships are designed to be loaded to 19 feet or more. For the rapid and safe movement of a ship in the 21-foot waterway there should be about 2 feet of water under its keel. The larger ships now in use, therefore, have reached the limit of draft that should be permitted in this waterway. If it were certain that ships no larger than the largest now in use would furnish the most economical transportation, the locks should be no larger than required to receive them. There may be, however, considerable development in length and beam, and if such an increase should prove practicable and economical, it would be a serious error if the locks were made too small. If, on the other hand, the locks were a little larger than needed, the cost would not be increased very much nor the operation of the canal impeded appreciably. The dimensions adopted—600 feet long and 60 feet wide—are sufficient for a ship 550 feet long over all and 58 feet beam. Such a ship would have about 25 per cent greater carrying capacity than the largest now on the lakes.

These dimensions provide for the passage of the larger ships singly.

The locks of the St. Marys Falls Canal were designed to pass fleets of four large ships at a single lockage whenever so many were in waiting, and in practice the average number of ships per lockage is about two. This canal offers the most conspicuous existing example of the handling of a large traffic through a canal with locks, and some reasons must be given for departing from such a precedent.

The first reason is that a lock large enough to contain a fleet of four of the largest ships likely to navigate the waterway would be large beyond precedent. The new or Poe lock at the St. Marys Falls Canal is 800 feet long and 100 feet wide. Before it was completed, ships of more than half its length were in use and the lock would receive only two of them at once. Within three years after its opening, ships were in use of more than half its breadth as well as more than half its length, and only one of them could be taken into the lock at one lockage. For the "type ship" in the 21-foot channel (see Appendix 5) the lock to pass four at once would have to be 1,020 feet long and about 106 feet wide. To pass ships of the larger size thought possible, 550 feet long and 58 feet beam, the lock should be 1,170 feet long and about 120 feet wide. The difficulties of operating such a lock would be very great.

The second reason is that each vessel would be delayed while other vessels were being placed in the lock. This is not of great moment at a single lock, but with the large number of locks on the deep waterway the aggregate loss of time would be a serious tax on navigation. It is believed that the waterway should be so designed as to provide the quickest transit for each ship.

The preceding reasons relate to the economy of the ship. A third reason for preferring the lock for a single ship is found in economy of water supply. This is of most importance on the Mohawk route, where it would be difficult to obtain a sufficient supply for the large locks.

Ocean ships have had a less rapid development than ships on the Great Lakes, but similar in kind. The controlling conditions are more complex than on the lakes; the depth in harbors varies greatly; the nature of the cargo, the number of ports of call, and the port facilities for handling freight differ from the simpler conditions and more perfect appliances on the lakes, and on many routes it is impracticable for large ships to be profitably employed.

The greater part of the freight transported by sea is carried in ships not exceeding 500 feet in extreme length and 55 feet beam. For passenger service large and fast ships are preferred by the traveling public. This fact has led to the building of larger and faster ships for a combined passenger and freight service than usually required for freight alone; yet the largest ships of the long-established Peninsular and Oriental Steamship Company which traverse the Suez Canal and visit East Indian and Australian ports do not exceed the dimensions

above named. One of the new ships of this line, the *Assaye*, launched in October, 1899, is only 450 feet long and 54 feet beam. The new ships of the White Star Line for the Australian trade are much larger, being about 575 feet long over all by 64 feet beam.

The most marked development in size of ocean ships has been on the North Atlantic route. This would seem particularly pertinent to the deep waterway, because the greater part of the materials passing through the deep waterway for export would cross the ocean by the North Atlantic route. The longest ships on this route are devoted wholly or mainly to the transportation of passengers. They would not traverse the deep waterway. The next in length are ships carrying both passengers and freight and running from 16 to 19 statute miles per hour. The largest of this class are the *Pennsylvania* and *Graf Waldersee*, of the Hamburg-American Line, 560 to 565 feet long and 62 feet beam; the *Cymric*, of the White Star Line, 600 feet long and 64 feet beam, and the *Ivernia* and *Saxonia*, of the Cunard Line, 600 feet long and 64½ feet beam. These ships when fully loaded draw upward of 30 feet in sea water, while the permissible draft in the 30-foot deep waterway would not much exceed 27 feet in fresh water, equivalent to a sea draft of about 26 feet There must be some ratio between length and draft for the best economical results.

This ratio between length and draft is treated very ably in a paper by Prof. J. H. Biles recently presented to the (British) Institution of Naval Architects. This paper contains estimates of cost of two series of ships, running from 500 to 700 feet in length. In the first series the full-load draft is uniformly 27 feet 6 inches. In the second series the draft increases from 27 feet 6 inches for the ship 500 feet long to 38 feet 6 inches for the ship 700 feet long, the ratio of length to draft being about 18. A comparison is then made of the cost of carrying a ton of cargo 5,000 nautical miles at a speed of 12 knots per hour in these ships. The results are shown in the following table:

| Length of ship—feet | 500 | 550 | 600 | 650 | 700 |
|---|---|---|---|---|---|
| First series, draft 27 feet 6 inches for all: | | | | | |
| Cost, in shillings, per ton of cargo | 8.6 | 9.0 | 9.6 | 10.4 | 11.2 |
| Second series, draft varying: | | | | | |
| Draft | 27′ 6″ | 30′ 3″ | 33′ 0″ | 35′ 9″ | 38′ 6″ |
| Cost, in shillings, per ton of cargo | 8.6 | 8.0 | 7.6 | 7.2 | 7.0 |

This table shows clearly the greater cost of transportation in large ships per ton of cargo on a limited draft, as well as the economy of transportation in large ships with draft increasing with length.

In order to check these results by an independent estimate with more complete details of the several elements of cost, one of the most prominent naval architects in the United States, Mr. Frank E. Kirby, was requested by the Board to prepare estimates of the cost of building, maintaining, and operating ships of various dimensions from 480

feet in length by 52 feet in breadth to 550 feet in length by 60 feet in breadth, all with a load draft of 27 feet. The estimates are given and discussed in Appendix 5. They show that the cheapest transportation through the 30-foot waterway from Duluth or Chicago to New York Harbor would be given by the ship 500 feet long. The beam of this ship was assumed to be 54 feet.

It is interesting to note that this length is practically the same as that of the largest existing ship on the Great Lakes—the *John W. Gates*—and that its beam is only 2 feet greater, while its draft exceeds that of the *Gates* by 7 or 8 feet. This analysis therefore supports the idea that the limit of size of lake boats has been nearly or quite reached unless the harbors and channels are made deeper.

The foregoing figures have been based on the assumption that the cargo would be of such density that the ships could be fully loaded. Certain classes of freight might require more space than a ship 500 by 54 feet affords. Professor Biles shows that the larger ship on constant draft gives greater proportional space. This might lead to the use of a small number of larger ships. Further improvements in terminal facilities and further economies in operating ships might tend in the same direction.

Although the contingency is extremely remote, it is conceivable that it may at some time become extremely desirable to pass war ships through the waterway. To pass our largest existing battle ships would require a width of locks of 75 feet, and it may be expected that larger ones will be built in the near future. A reasonable provision for future increase would be made if the width were fixed at 80 feet.

Among the industries which it is expected the waterway will develop at lake ports is that of building ocean ships. With locks 80 feet wide this industry could include the building of battle ships.

With these several considerations before it, the Board decided to estimate for the 30-foot waterway, locks 740 feet in length from quoin to quoin, giving an available length of about 700 feet and 80 feet in width. The additional width of lock increases the time required for filling and emptying the lock, and thus reduces to some extent the commercial usefulness of the waterway. There will be difference of opinion as to whether the possible military value and the possible service to shipbuilding interests justify the infliction of this loss on the interests of navigation.

In view of the result of the investigation regarding the length of ship to give the cheapest transportation, the length of lock adopted may seem too great. In single locks or when two lifts are combined it is proposed to place intermediate gates in the locks, so that a shorter chamber can be used when desirable. In these cases the long lock is objectionable on account of first cost only. Where more than two lifts are combined the intermediate gates are omitted, and if the adopted length of lock is greater than necessary it affects unfavorably

both first cost and facility of operation; but it must not be forgotten that successive economies in cost of transportation have almost invariably favored a larger ship, and it is judicious to make a large provision for possible increase.

## CAPACITY OF A LOCK OR SYSTEM OF LOCKS FOR THE PASSAGE OF SHIPS.

It is necessary to show what capacity for traffic the waterways proposed will have. It is obvious that the limit is fixed by the locks. The method followed for investigation is to calculate the maximum capacity of a lock or series of locks to pass ships, and then to apply to this theoretical result a coefficient derived from experience at the St. Marys Falls Canal, to obtain the practical capacity. The discussion of several problems of the deep waterway requires a determination or assumption as to the average size of ships that will traverse it. The question is taken up briefly elsewhere, with the result that the average net register of ships in the 21-foot waterway is taken at 2,500 tons and in the 30-foot waterway at 3,000 tons.

The greater part of the freight carried through the deep waterway will be bound eastward. It has been estimated that the west-bound freight will be one-third as much. Through the St. Marys Falls Canal the west-bound freight in 1899 was about 22 per cent of the east-bound. For the present purpose it is assumed that ships east bound will carry full loads and when bound west will carry one-fourth as much. A ship fully loaded carries about twice its net registered tonnage. The total freight carried will therefore be, on the assumption given, two and one-half times its net register for the round trip, or an average of one and one-fourth times its net register for each passage. In calculating the capacity of a lock it is more convenient to deal with the net registered tonnage.

The delay at a lock is calculated from the following data:

1. A ship approaching a lock will reduce speed at the rate of 1 mile per hour while moving 400 feet.

2. When within 700 feet of the lock-gate quoin its speed will have been reduced to 2 miles per hour.

3. If the lock is open, the ship will continue at this rate until its stern is within 150 feet of the lock-gate quoin (200 feet if moving downstream). It will come to a full stop in the next 200 feet, backing the wheel if necessary.

4. If the lock is not ready, the ship, on arriving within 700 feet of the lock-gate quoin with a speed of 2 miles per hour, will come to a full stop within the next 200 feet, backing the wheel if necessary, and tie up. When the lock is opened, the ship will acquire a speed of 2 miles per hour in moving 400 feet and continue at this rate into the lock, stopping as before.

5. The time required for opening or closing a pair of gates is taken at two minutes.

6. When the ship is brought to a stop in the lock, it will move forward until its bow is within 50 feet of the next quoin and tie up. This movement will be made while the gates are being closed.

7. The time for filling or emptying a single lift, for filling the upper lock of a series, and for emptying the lower lock of a series is the theoretical time divided by the coefficient 0.75. For the filling or emptying of intermediate locks of a series the coefficient is taken at 0.66. The coefficient is smaller in this case on account of the greater length of the culverts.

8. A ship leaving a lock acquires a speed of 2 miles per hour in moving 400 feet, increases speed to 4 miles per hour in the next 600 feet, and then proceeds to increase speed at the rate of 1 mile per hour while moving 400 feet until full speed is attained.

*Lockage capacity of the 21-foot waterway.*—The maximum capacity of a single lock would be developed if ships were constantly in waiting and were passed alternately up and down. The minimum time required for the passage of two ships through a lock of 20 feet lift would be as follows:

| | | |
|---|---|---|
| From tie-up place into lock, first ship | minutes | 9.3 |
| Closing lower gates | do | 2.0 |
| Filling lock | do | 5.1 |
| Opening upper gates | do | 2.0 |
| Leaving lock passing waiting ship | do | 8.1 |
| Moving into lock from tie-up place, second ship | do | 9.0 |
| Closing upper gates | do | 2.0 |
| Emptying lock | do | 5.1 |
| Opening lower gates | do | 2.0 |
| Leaving lock and passing waiting ship | do | 8.1 |
| Time for two ships | do | 52.7 |
| Time per ship | do | 26.35 |
| Number of ships in a navigation year of two hundred and thirty-seven days | | 12,052 |
| Annual net registered tonnage, at 2,500 tons per ship | tons | 32,380,000 |
| Annual freight traffic, assumed to be one and one-fourth times the registered tonnage | tons | 40,475,000 |

This would be the maximum traffic capacity if the lock were in constant operation with no delays whatever. Notwithstanding the greatest perfection in operating machinery, the utmost skill in handling it, and the greatest care in the moving of ships at the locks, accidents and delays will occur, increasing considerably the average time of lockage. The condition that ships shall always be in waiting is inadmissible, because it would involve so much aggregate delay to shipping as to make the route unprofitable. By reason of varying weather, different rates of speed, and delays in receiving freight, the distribution of ships along the route is far from uniform, and as the traffic

capacity of a lock is approached the delays to shipping augment in rapidly increasing ratio. Experience at the St. Marys Falls Canal shows this very clearly.

The greatest traffic through this canal with only one lock in operation occurred in 1894 through the Weitzel lock. The delays to ships were so great that it may be considered the practical traffic capacity of the lock was reached. The canal records enable a comparison to be made of the theoretical (or calculated) and the practical traffic capacity of the locks of the deep waterway.

In applying the data it is necessary to make two corrections, which depend on the character of the shipping. These are: First. The ships which will traverse the deep waterway are assumed to average 2,500 tons net register (for the 21-foot waterway). This is more than twice the mean tonnage of the ships traversing the St. Marys Falls Canal in 1894, and the larger ships require more time in handling. Second. Two or more ships are usually locked through together at the St. Marys Falls Canal, while it is expected that ships will pass singly through the locks of the deep waterway. The time required for lockage should therefore be less for the deep waterway. A third correction depends on the time required for filling or emptying the lock. This will be less for the lock of 20-foot lift in the 21-foot-deep waterway than for the Weitzel lock.

The following data relating to the traffic of 1894 through the Weitzel lock are taken from the official report of the engineer officer in charge:

| | |
|---|---|
| Net registered tonnage | 13,110,366 |
| The number of lockages | 6,431 |
| The number of ships | 14,491 |
| Average time of lockage | 40 34″ |
| Average time in lock for each ship | 34 32″ |

The average number of ships per lockage was $\frac{14491}{6431} = 2.25$.

The net registered tonnage given above is taken to represent the practical traffic capacity of the Weitzel lock. It is to be shown what the corresponding capacity would have been if the ships had been locked singly, if the net registered tonnage of ships had averaged 2,500, and if the time for filling and emptying the lock had been the same as calculated for the lock of 20-foot lift in the 21-foot waterway.

At the St. Marys Falls Canal the time for a lockage is taken as beginning when the bow of the ship enters the lock and ending when the stern leaves it. The entire cycle from the beginning of one lockage to the beginning of the next is greater. Sufficient time must be added to the given time of lockage to permit the ship to move from the outlet of the lock past the waiting ship (which is supposed to be lying as near the lock as practicable) and for the movement of the second ship from its waiting place to the entrance to the lock. The second ship can not move until the first ship passes it. The time

required for these two movements has not been observed at the St. Marys Falls Canal. It has been calculated for the deep waterways to be 8 minutes. For the smaller ships of 1894 it would probably have been about two-thirds as much, or 5.3 minutes. Adding this to the reported time of lockage, there results when lockages are consecutive—

Interval from the commencement of one lockage to the commencement of the next at the St. Marys Falls Canal in 1894, $40.5+5.3=45.8$ minutes.

It is next to be determined how much this lockage interval would be reduced if ships were locked singly.

Let $n$ = number of ships per lockage.

Let $x$ = time of ship in lock when locked singly.

Let $y$ = additional time required to move another ship into or out of the lock.

The additional time per lockage and additional time per ship will be as per following table:

| Number of ships per lockage. | Delays to ships while others are entering lock. | | | | Delays to ships while others are leaving lock. | | | | Total delay to ships. | Average delay per ship. | Lockage time increased. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | To first ship. | To second ship. | To third ship. | To fourth ship. | To first ship. | To second ship. | To third ship. | To fourth ship. | | | |
| $n=1$ ... | 0 | ..... | ..... | ..... | 0 | ..... | ..... | ..... | 0 | 0 | 0 |
| $n=2$ | $y$ | 0 | ..... | ..... | 0 | $y$ | ..... | ..... | $2y$ | $y$ | $2y$ |
| $n=3$ | $2y$ | $y$ | 0 | ..... | 0 | $y$ | $2y$ | ..... | $6y$ | $2y$ | $4y$ |
| $n=4$ ... | $3y$ | $2y$ | $y$ | 0 | 0 | $y$ | $2y$ | ..... | $12y$ | $3y$ | $6y$ |

From this table we can deduce the following formulæ:

$$\text{Time of ship in lock} = x+(n-1)\ y.$$

$$\text{Time of lockage} = x+2\ (n-1)\ y.$$

For 1894, $n=2.25$, and the equations become

$$x+(2.25-1)\ y=34.5.$$

$$x+2\ (2.25-1)\ y=40.5.$$

Whence $y=4.8$ minutes.

$x=28.5$ minutes=time of ship in the Weitzel lock in 1894 when locked singly. The entire interval between the commencement of one lockage and the commencement of the next would have been 5.3 minutes more, or $28.5+5.3=33.8$ minutes.

With the larger ships assumed for the deep waterway, this interval would be greater on account of the additional time required to move the larger ship from the waiting place into the lock and from the lock past the waiting place, including the movement in the lock as well as in the approaches. The calculated time for these movements is 17.34 minutes; one-third of this is 5.8 minutes. Adding this to 33.8, there

results 39.6 minutes as the time required for locking the assumed deep-waterway ship through the Weitzel lock. If the deep-waterways lock of 20 feet lift were substituted for the Weitzel lock, the lockage time would be reduced by reason of quicker filling and emptying. This reduction would be about 3 minutes, making interval from commencement of one lockage of a single ship to commencement of next through the deep-waterways lock of 20 feet lift (21-foot waterway)=39.6−3.0=36.6 minutes.

This is larger than the calculated time given on page 135, as it ought to be, because it includes delays of all kinds in the locks, but it does not include delays of ships awaiting lockage. It is to be compared with the corresponding time actually required for fleet lockages in 1894, given on page 137 as 45.8 minutes. It may be presumed that if the lockage time were reduced from 45.8 to 36.6 minutes the number of lockages would be correspondingly increased and the traffic could be augmented in like ratio with no more delay to waiting ships. The actual number of lockages having been 6,431, the number through the deep-waterways lock with one ship of 2,500 tons net register per lockage would be—

$$6{,}431 \times \frac{45.8}{36.6} = \text{---------- } 8{,}048$$

| | |
|---|---|
| Net registered tonnage, at 2,500 tons per ship | 20,120,000 |
| Freight tonnage, one and one-fourth times net registered tonnage | 25,150,000 |

With this traffic the delays to waiting ships would be about the same as occurred at the St. Marys Falls Canal in 1894, and it may be considered the practical maximum capacity of a single lock of 20 feet lift in the 21-foot waterway. It is about 0.621 of the calculated maximum capacity of this lock. This coefficient will be applied in the following cases to the calculated maximum capacity to obtain the practical capacity of the several lockage systems.

This deduction of practical capacity of the lock of the deep waterway is based upon the best existing data. Although certain factors introduced are derived from assumptions as to movement of ships, it is not believed that any error contained in them can affect in an important degree the traffic capacity obtained from the discussion.

If two successive lifts of 20 feet each were combined into one flight, the minimum time required for the passage of two ships in opposite directions would be 82 minutes, or 41 minutes per ship. This would make the calculated maximum capacity of the system 26,012,000 freight tons per navigation year of 237 days, or, applying the coefficient, 0.621, a practical maximum capacity of 16,153,000 tons.

If three or more locks are combined into one flight, the capacity of the system will be still less. If the system is doubled, ships will be passed down in one flight and up in the other. The minimum interval

between two ships will be as per following statement. Take the Lewiston flight, with locks of 40 feet lift, as representing the worst case:

| | Minutes. |
|---|---|
| From tie-up place into lock (from below) | 9.3 |
| Closing gates | 2.0 |
| Filling lock | 5.8 |
| Opening second gates | 2.0 |
| Moving into second lock | 6.7 |
| Closing second gates | 2.0 |
| Emptying first lock | 7.2 |
| Opening upper gates | 2.0 |
| Interval | 37.0 |

With an interval between ships of 37 minutes, the number of ships in the navigation year of 237 days would be 9,224; net registered tonnage at 2,500 tons per ship, 23,060,000; freight tonnage one and one-fourth times registered tonnage, 28,825,000. For the duplicate line of locks the capacity would be the same, making the calculated maximum traffic = 28,825,000 × 2 = 57,650,000 tons. The practical maximum=0.621 of this=35,801,000 tons.

*Lockage capacity of the 30-foot waterway.*—Following the same method as for the 21-foot waterway, the minimum time required for the passage of two ships in opposite directions through a single lock of 20 feet lift would be as follows:

| | Minutes. |
|---|---|
| From tie-up place into lock, first ship | 9.6 |
| Closing lower gates | 2.0 |
| Filling lock | 8.4 |
| Opening upper gates | 2.0 |
| Leaving lock and passing waiting ship | 8.3 |
| Moving into lock from tie-up place, second ship | 9.3 |
| Closing upper gates | 2.0 |
| Emptying lock | 8.4 |
| Opening lower gates | 2.0 |
| Leaving lock and passing waiting ship | 8.3 |
| Time for two ships | 60.3 |
| Time per ship | 30.15 |
| Number of ships in a navigation year of 237 days | 11,319 |
| Annual net registered tonnage, at 3,000 tons per ship ..... tons | 33,957,000 |
| Annual freight tonnage, assumed to be one and one-fourth times the registered tonnage ..... do | 42,446,000 |

This is the calculated maximum. Using the same coefficient as before, 0.621, the practical maximum would be 42,446,000 × 0.621 = 26,359,000 for a single lock of 20-foot lift in the 30-foot waterway.

If two successive lifts of 20 feet each were combined into one flight, the minimum time required for the passage of two ships in opposite directions would be 96 minutes, or 48 minutes per ship. This would make the calculated maximum capacity of the system 26,662,000 net

tons of freight in a navigation year of 237 days, or a practical maximum of 0.621 of this = 16,557,000 tons.

With three or more locks combined in one flight the capacity of the system will be less, as already noted in discussing the locks for the 21-foot waterway, and if greater capacity is desired the system must be doubled, one flight of locks being used for ships bound down, the other for ships bound up. The maximum capacity of a flight depends on the minimum interval required between ships. Taking the Lewiston flight with a lift of 40 feet at each lock, the minimum interval between ships will be as follows:

| | Minutes. |
|---|---|
| From tie-up place into lock | 9.6 |
| Closing first gates | 2.0 |
| Emptying first lock | 9.6 |
| Opening second gates | 2.0 |
| Moving into second lock | 7.1 |
| Closing second gates | 2.0 |
| Filling first lock | 11.9 |
| Opening first gates | 2.0 |
| Interval between ships | 46.2 |

With an interval between ships of 46.2 minutes the number of ships in a navigation year of 237 days would be 7,387. Net registered tonnage at 3,000 tons per ship, 22,161,000 tons. Freight tonnage, one and one-quarter times registered tonnage, 27,701,000 net tons.

For the duplicate flight of locks the capacity would be the same, making the calculated maximum capacity—

| | Tons. |
|---|---|
| 27,701,000 × 2 = | 55,402,000 |
| The practical capacity = 0.621 of this | 34,405,000 |

This is less than the capacity of the same system of locks in the 21-foot waterway, although the assumed average tonnage per ship is 20 per cent greater. The result illustrates the cost to purely commercial navigation interests of adopting lock dimensions much greater than commercial ships are likely to require in order to make the waterway more useful for war purposes.

The Board assumes, for the discussion of technical questions affecting the waterway, that the annual traffic will be 25,000,000 tons. It is believed that this can be passed through a single lift by a single lock; but the capacity of the lock will be nearly reached, and the delays to ships while awaiting lockage will be considerable. At the St. Marys Falls Canal in 1894 the delay to ships while awaiting lockage was an average of 3½ hours for each. The delays were due mainly to bad weather, causing ships to arrive at times in fleets. These delays increase rapidly when the waterway is overcrowded.

In 1890, with a tonnage of 8,500,000 tons, the average delay was less than 1½ hours. In 1896, when the Canadian lock was in successful operation and the new Poe lock afforded some relief, the delays were

reduced to less than one hour, although the tonnage had increased since 1894 from 13,100,000 to 17,200,000. In 1897 all three locks of the system were in successful operation, and the average delay was only one-fourth hour, with a tonnage of 17,600,000.

The preceding estimates of capacity of locks have been based on the record of the St. Marys Falls Canal in 1894. If the treatment is correct, it follows that when the annual freight tonnage in the 21-foot waterway reaches 25,150,000, the delays at that point with only a single lock in use would be about 3½ hours per ship; in the 30-foot waterway this delay would occur when the annual freight tonnage reached 26,359,000. This unequal distribution of shipping would probably be greater at the St. Marys Falls Canal than at any other lake point on the route, but delays of a similar character will occur on the Mohawk route at Oswego to ships bound east and at Albany to ships bound west. On the St. Lawrence-Champlain route similar delays will occur at the Galops Rapids lock to ships bound east and at the Troy lock to ships bound west. The delays at the termini of the Niagara section would be much less on account of the greater capacity of the double lockage system provided there.

The delay to ships at intermediate locks on each of the divisions of the waterway will be small, because the terminal locks will distribute them. If all ships moved at uniform rates, the delay would be inappreciable, but as some will move more rapidly than others, there will be small delays at every lock or flight of locks, and the aggregate will be of some importance.

The doubling of locks, which increases the capacity and reduces the delays, has the further advantage that if one of the locks or flights is disabled traffic can be continued through the other, and a total stoppage of traffic averted. The double system has been adopted where two or more lifts are combined, because the anticipated traffic requires it. Careful consideration has been given to the question of doubling locks at single lifts (where a single lock will pass the anticipated traffic), in order to lessen the danger of a stoppage of navigation by the disabling of a lock; but it is believed that the danger of such a contingency is not great enough to justify the large increase in cost.

### DIMENSIONS OF DUPLICATE LOCKS.

Where the locks of the 21-foot waterway are to be doubled, the second lock is designed to be of the same width as the first, viz, 60 feet. For the 30-foot waterway the width of 80 feet was fixed, as already stated, to permit the passage of war ships and to facilitate the building of large ships for ocean traffic at shipyards on the lakes. A lock 70 feet wide would pass the largest existing commercial ship, and a width of 60 feet would probably be sufficient for nearly all the ships which would use the waterway. The width of 60 feet was therefore fixed for the second line of locks in the 30-foot waterway.

With this project executed, ships of the largest class could only be passed in the large locks. If such a ship were going in the direction of the traffic through those locks no difficulty would occur; if going in the opposite direction it would interfere with traffic to some extent. Where two lifts only are combined into one system the interference would be slight and unimportant, but where more than two lifts are combined, notably in the case of the six combined locks of the Lewiston flight, it would be necessary practically to fill (or to empty according to direction of ship's movement) all the locks in the flight before the ship could enter the second lock, and the delay to the ship would be considerable.

All ships waiting to pass the chain in regular order would also be delayed. If the proportion of ships exceeding 60 feet in breadth should be large, and if the traffic through the waterway were great, the delays would affect the usefulness of the waterway to a serious extent. The proposed width of 60 feet for the duplicate locks would then prove insufficient, and a width of 65 feet or more would be required. The cost of increasing the width 5 feet would be about $430,700 for the entire waterway.

### LIFTS OF LOCKS.

In a few localities the topography favors larger lifts than have been adopted heretofore. In all these localities solid-rock foundations are available, and will carry safely any load that the largest lifts would impose on them. Other points, however, required examination.

The first point was whether gates could be designed to safely stand the extreme heads which would result from the project investigated by the Board. The Lewiston flight, for example, with lifts of 40 feet, would subject the intermediate gates in the 30-foot waterway to heads in some cases as great as 77 feet. The study of this subject, given in detail in Appendix No. 2, showed that gates to sustain this head are entirely practicable.

The next point was in regard to the relative usefulness for navigation of low and high lifts. With low lifts the interval between ships would be less and the maximum capacity of the waterway would be greater. This may be illustrated by reference to the Lewiston flight. If the lifts were 20 feet each, the minimum interval between two ships in the 21-foot waterway would be as follows:

| | Minutes. |
|---|---|
| For movement of ship from tie-up place into lock | 9.3 |
| Closing lower gates | 2.0 |
| Filling lower lock | 4.1 |
| Opening second gates | 2.0 |
| Moving ship into second lock | 6.7 |
| Closing second gates | 2.0 |
| Emptying lower lock | 5.1 |
| Opening lower gates | 2.0 |
| Interval | 33.2 |

With this interval between ships the number of ships in a navigation year of 237 days would be 10,280 in each flight, and the net registered tonnage, at 2,500 tons per ship, 25,700,000. Comparing this with the corresponding estimate for 40-foot lifts (see p. 139), the reduction in capacity resulting from doubling the lift appears to be about 10 per cent. If the waterway should become crowded, the delays to individual ships while awaiting lockage would be a little greater with high lifts than with low ones, because the traffic limit would be reached sooner; but unless the traffic exceeds present estimates the delay in either case would be inconsiderable.

A more important feature is the delay that would result to every ship if the projected lifts were reduced. Again using the Lewiston flight for comparison, the estimated minimum time required to pass the 6 locks of 40 feet each in the 21-foot channel is 108 minutes. If the lifts were 20 feet each, 12 locks would be required, and the minimum time for passing them would be 186 minutes, giving a greater delay in the low-lift system of 78 minutes, to which every ship would be subjected at this single locality. This is the minimum possible, and will be exceeded, because the unforeseen delays in passing through 12 locks are greater than in passing through 6.

A third point affecting the lift of locks is the cost of the project. No general rule can be laid down and each case must be studied by itself. No estimate has been made of the cost of the Lewiston flight with 20-foot lifts, but comparative estimates with lifts of 30 and 40 feet show that the system with 30-foot lifts would cost $4,600,000 more than with 40-foot lifts, and a similar further increase may be expected if the lifts were reduced to 20 feet.

From these considerations there appears no doubt that the high lifts adopted are in every way feasible, cheaper to construct, and better adapted to the use of navigation than those heretofore in common use.

## GENERAL DESCRIPTION OF LOCKS.

Under this head it may be well first to repeat the lateral dimensions already given.

For the 21-foot waterway: All locks to be 600 feet long between quoins of lock gates and 60 feet wide.

For the 30-foot waterway: Single locks to be 740 feet long between quoins of lock gates and 80 feet wide. Where two or more lifts are combined into a flight, two lines of locks are provided. The locks in one line have the same dimensions as single locks; in the other line the length remains the same, but the width is reduced to 60 feet. All single locks and combined locks, not exceeding two lifts in series, are provided with intermediate gates dividing the chamber into two unequal parts, so that the entire lock or a part thereof can be used.

In both the 21-foot and the 30-foot waterways guard gates are placed

at the head and foot of each single lock and at the head and foot of each flight, so that any lock can be quickly prepared for pumping out or draining. This provision is made in all the locks at Sault Ste. Marie and has proved valuable.

The lock walls are designed to resist overturning by gravity alone, except at the gate recesses of the middle wall separating the double flight on the Lasalle-Lewiston line. At these places if one of the locks is pumped out while the opposite one is in operation, a contingency very likely to arise, the thickness adopted is not quite sufficient to wholly prevent tension in the masonry. Three alternatives were considered to meet this: First, to introduce enough steel members in the base of the wall to take the tension. The cost of this would be $163,200 for the entire line. Second, to increase the thickness for a length of 120 feet at the gates. This would make the chambers of the locks several feet wider than the entrances to them. The increased width would not facilitate the passage of ships in any respect, but, on the contrary, would delay them by reason of the greater time required for filling and emptying locks. This alternative was therefore rejected. Third, to increase the thickness of the middle wall for its whole length, the thickness at the gates recesses being the same as in the preceding alternative, making it a gravity section, but with a large surplus over theoretical requirements everywhere except at the gates. The cost of the additional thickness would be about $542,400 for the entire line. It would exceed the cost of the first alternative by $379,200. The first alternative was therefore adopted.

All lock floors are in the form of inverts. At the head and foot of each lock the thickness of the invert is sufficient to withstand the maximum difference in head at the gates. In the interior of the chamber the thickness is reduced, the amount of reduction depending on the character of the rock foundation. The strength of the inverts as shown on the plans is doubtless excessive where rock is sound, but without further information by means of borings with the diamond drill or actual examination of the excavated lock pits it is not prudent to make a close estimate in this respect. An additional reason for this liberal provision is found in the fact that lock excavation and construction is work of an extremely hazardous nature with large contingencies, and if economies may be effected in some localities in the extent and cost of inverts they are likely to be balanced by unexpected difficulties and expenses in other localities.

### CULVERTS FOR FILLING AND EMPTYING LOCKS.

For filling and emptying the locks a culvert 87 square feet in cross section is placed in each wall, extending its whole length. Each culvert communicates with the chamber through a large number of small branches, each 9 square feet in cross section. The combined area of the cross sections of the branches is about double the cross section of the culverts, this excess being provided in order to reduce the force

of the currents into the lock. The spacing between the branches becomes less toward the foot of the lock, because the amount of water issuing from each in filling diminishes from the head toward the foot, and it is desirable to make the amount of discharge from the culverts as nearly uniform as practicable per unit of length.

The culverts are of the same dimensions for locks of all sizes. It may be asked why larger culverts were not used for the larger locks. The speed of filling, when the culverts are properly designed, is not limited by the behavior of ships in the locks, but by the effect of the current caused in the immediate vicinity. This effect is practically independent of the area of the locks. The culverts adopted are believed to be as large as it is prudent to make them. If the principle of dimensioning the culverts according to the currents induced in the waterway were carried out rigidly it would lead to a reduction of size of culvert with increase in lift of lock; but this would greatly increase the time required for filling or emptying high-lift locks. The difficulty can be met by opening the culverts only partially until the first and strongest rush of water is past.

The culverts at the inlets and for some distance inward are to be lined with granite; the remainder, and greater part, of the length of the main culverts is to be lined with hard brick, equal in quality to the best paving brick. This is in conformity with the practice at the Manchester Canal. The branches from the culverts to the lock chambers are to be lined with cast iron. These branches are of smaller dimensions than usual in foreign practice. It will be noted that in height and direction they are designed to discharge under the hull of a ship lying in the lock, not against it. In the locks of greatest lift it may possibly be necessary to line the culverts with cast iron. The upper lock of the Lewiston flight will be filled, and the lower emptied with a maximum head of 40 feet, while in the intermediate locks the maximum head will be 80 feet. The current due to a head of 80 feet will have twice the velocity and four times the destructive effect of one due to 20-foot head. A continuous culvert lining of 1½ inches of cast iron, with 50 per cent added for flanges and stiffening ribs, would weigh about 3,000,000 pounds per lock, and would add about $90,000 to its cost. For the six locks of the Lewiston flight and the two combined locks of 40 feet each near the foot of the Lasalle-Lewiston route the additional cost would be about $1,440,000.

The inlets and outlets of the culverts are designed to impede the flow of water as little as practicable. The water for filling a single lock, or the upper lock of a flight, is received immediately above the gate and discharged along the chamber, the average movement of water from the pool above the gates to the chamber being about half the length of the lock. The water travels about the same distance in the culvert in emptying a single lock or the lower lock of a flight.

In these cases a coefficient of 0.75 is applied to the theoretical

velocity in calculating time required for filling or emptying a lock. This is considerably larger than that deduced from observations on the locks of the St. Marys Falls Canal, where the design of the culverts is such that the loss of head is very great. It is somewhat less than that observed by General Abbot at the Manchester Canal, where the culverts are carefully designed to avoid loss of head. For the filling and emptying of intermediate locks in a flight the average travel of water in the culverts is a full lock length; the coefficient of velocity should therefore be smaller and is taken at 0.66.

The valves or gates for opening and closing the culverts are to be placed in the main culverts near the lock gates. They are designed to be of the form known as Stoney sluices, counterbalanced, and moving on live rollers to reduce friction.

### CHARACTER OF MASONRY.

All the masonry of the locks except the culvert linings already mentioned, the hollow quoins, and the upper portions of the miter sill walls is to be of concrete. A thickness of about 2 feet in the face of the lock walls and all the concrete in the miter sills, head wall, and invert are designed to be of concrete containing mortar of one packed volume of Portland cement to two packed volumes of sand, with as much stone as practicable. A cheaper concrete, containing 1:3 mortar with Portland cement, will suffice for the body of the main walls, and a still cheaper mixture, made with natural cement, is intended for a small portion of the middle wall between duplicate locks, where weight only is needed.

### LOCK GATES.

The lock gates are designed to be of steel. Excepting the intermediate gates of the 40-foot lifts on the Niagara Canal lines, there is no air chamber, the skin being on the upstream side only and the gate hangings having ample strength to sustain the entire weight. In the excepted cases a small air chamber is provided near the bottom of the gate. The design of the gates and the theory of strains in them have received, it is believed, more careful, extended, and practical study than heretofore given to the subject. (See Appendix No. 2.) Miter gates, single-leaf swinging gates, and single-leaf rolling or sliding gates were designed and compared, resulting in the selection of the standard miter gates. The design adopted is of simple outline, with cheap shop details and of ample strength.

### OPERATING MACHINERY.

It has not seemed necessary to take up the subject of operating machinery in detail. It appears probable that electrical machinery will be found most suitable, but the development in this line is so rapid that any design made now would almost certainly be out of date in less than five years. It has therefore seemed more judicious to merely include in the estimate a lump sum sufficient to provide hydraulic or pneumatic machinery of ordinary character.

## ESTIMATE OF COST.

The details of the estimate of cost of a standard lock of 20 feet lift and of the upper flight at Lewiston, for both depths of channel, are given in the following tables. Excavation and back filling are not included, but are provided for in the general estimates for the waterway.

TABLE NO. 1.—*Cost of standard single lock of 20 feet lift with intermediate gates.*

[Thirty-foot channel.]

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Portland-cement concrete.....cubic yards | 134,007 | $6.00 | $804,042 |
| Granite miter sills.....do | 585 | 45.00 | 26,325 |
| Granite hollow quoins and culvert linings.....do | 933 | 55.00 | 51,315 |
| Brick.....do | 1,417 | 12.00 | 17,004 |
| Structural steel.....pounds | 2,209,000 | .05 | 110,450 |
| Steel castings.....do | 83,200 | .06 | 4,992 |
| Steel forgings.....do | 12,100 | .10 | 1,210 |
| Bronze bushings.....do | 3,900 | .40 | 1,560 |
| Iron anchor bolts.....do | 98,560 | .03 | 2,957 |
| Iron port castings.....do | 342,000 | .025 | 8,550 |
| Cast iron pipe.....do | 17,415 | .014 | 244 |
| Timber, oak.....1,000 feet B. M. | 60.204 | 50.00 | 3,010 |
| Total cost | | | 1,031,659 |

TABLE NO. 2.—*Cost of a standard single lock of 20 feet lift.*

[Twenty-one-foot channel.]

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Portland-cement concrete.....cubic yards | 83,200 | $6.00 | $499,200 |
| Granite miter sills.....do | 347 | 45.00 | 15,615 |
| Granite hollow quoins and culvert linings.....do | 614 | 55.00 | 33,770 |
| Brick.....do | 1,215 | 12.00 | 14,580 |
| Structural steel.....pounds | 946,000 | .05 | 47,300 |
| Steel castings.....do | 63,200 | .06 | 3,792 |
| Steel forgings.....do | 9,200 | .10 | 920 |
| Bronze bushings.....do | 2,800 | .40 | 1,120 |
| Iron anchor bolts.....do | 63,040 | .03 | 1,891 |
| Iron port castings.....do | 273,600 | .025 | 6,840 |
| Cast-iron pipe.....do | 11,880 | .014 | 166 |
| Timber, oak.....1,000 feet B. M. | 34.776 | 50.00 | 1,739 |
| Total cost | | | 626,933 |

TABLE NO. 3.—*Cost of Lewiston flight of 6 locks, lifts 40 feet each.*

[Thirty-foot channel.]

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Portland cement concrete.....cubic yards | 1,654,819 | $6.00 | $9,928,914 |
| Natural cement concrete.....do | 145,567 | 3.00 | 436,701 |
| Granite miter stills.....do | 2,789 | 45.00 | 125,505 |
| Granite hollow quoins and culvert linings.....do | 8,707 | 55.00 | 478,885 |
| Brick.....do | 15,985 | 12.00 | 191,820 |
| Structural steel.....pounds | 12,488,100 | .05 | 624,405 |
| Steel castings.....do | 3,648,660 | .06 | 218,920 |
| Steel forgings.....do | 45,000 | .10 | 4,500 |
| Bronze bushings.....do | 15,000 | .40 | 6,000 |
| Steel in middle wall.....do | 4,080,000 | .03 | 122,400 |
| Iron anchor bolts.....do | 397,600 | .03 | 11,928 |
| Iron port castings.....do | 4,185,000 | .025 | 104,625 |
| Cast iron pipe.....do | 2,243,895 | .014 | 31,415 |
| Cast iron in stairs.....do | 172,800 | .03 | 5,184 |
| Timber, oak.....[1] B. M. | 108.144 | 50.00 | 5,407 |
| Total cost | | | 12,296,609 |

[1] 1,000 feet.

TABLE NO. 4.—*Cost of Lewiston flight of 6 locks, lifts 40 feet each.*

[Twenty-one foot channel.]

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Portland cement concrete.....cubic yards.. | 1,079,580 | $6.00 | $6,477,480 |
| Natural cement concrete.....do.... | 93,721 | 3.00 | 281,163 |
| Granite miter sills.....do.... | 2,348 | 45.00 | 105,660 |
| Granite hollow quoins and culvert linings.....do.... | 8,193 | 55.00 | 450,615 |
| Brick.....do.... | 12,269 | 12.00 | 147,228 |
| Structural steel.....pounds.. | 8,686,000 | .05 | 434,300 |
| Steel castings.....do.... | 2,754,600 | .06 | 165,276 |
| Steel forgings.....do.... | 45,000 | .10 | 4,500 |
| Bronze bushings.....do.... | 14,600 | .40 | 5,840 |
| Iron anchor bolts.....do.... | 364,480 | .03 | 10,934 |
| Iron port castings.....do.... | 3,364,200 | .025 | 84,105 |
| Cast iron pipe.....do.... | 1,902,060 | .014 | 26,629 |
| Cast iron in stairs.....do.... | 172,800 | .03 | 5,184 |
| Timber, oak.....[1]B. M.. | 153,992 | 50.00 | 7,700 |
| Total cost..... | | | 8,206,614 |

[1] 1,000 feet.

Respectfully submitted.

ALFRED NOBLE.

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

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## APPENDIX NO. 2.

### LOCK GATES.

DETROIT, MICH., *June 1, 1900.*

GENTLEMEN: I submit the following report upon the work done in making designs and estimates of the gates to be used in the locks of the various deep waterway routes investigated by the Board:

As a preparation for the design of the gates, the plans of many existing large locks were carefully studied and the literature upon the subject, both in English and in foreign languages, was made the subject of an extended research. A list of the authorities consulted upon the subject of mitering gates is given at the end of this report, with a brief note in regard to each. It is believed that the list is quite complete, covering nearly all that has been written upon the subject.

An investigation was made to determine whether some one of the numerous forms of single-leaf gate or the mitering gate is the more desirable type for the work in hand. The result was the adoption of the mitering gate as a basis of the designs and estimates.

A study was then made of the relative merits of the horizontal and vertical systems of framing for mitering gates, resulting in the adoption of the horizontal system.

Steel mitering gates of the horizontally framed type having been decided upon, a lengthy investigation was made to determine the rise of sill and the form, whether girder or arch, of horizontal frame which

will give the best results when economy of construction and facility of operation are considered. The question of the relative economy of the arch and girder form of horizontal frame has been a mooted one for a long time. The result of the investigation was the adoption of a rise of sill of one-fifth the width of the lock for all cases, and the adoption of a horizontal frame straight on the downstream side and curved on the upstream side, with depths varying for different widths of lock.

This is the so-called girder type. It was found that it presents advantages of greater stiffness and requires a shallower recess in the side wall than the arch form, and that, considering the state of the labor and steel markets at the present time and during the last decade, it is actually cheaper.

The detailed design of the gates for the 60 and 80 foot locks, 21 and 30 feet depth of water on sill and lifts varying from 10 to 50 feet, was then proceeded with. The accompanying general drawings, plates 70, 71, 72, 73, and 74, show typical designs for a number of cases. While only a limited number of drawings are shown, it is believed that they give all the important features of the design.

For the quoin and miter posts, wooden-bearing pieces were used on gates having the lighter pressures, but it was found necessary to use metal in some of the gates for locks of very high lifts.

A study was made of the variation in the position of the center of pressure at the miter and its influence in determining the most economical form of horizontal frame. The results of this study are given later.

The use of air chambers and rollers to reduce the reaction upon the anchorage and pivot was considered and rejected except in the case of gates weighing more than 500,000 pounds per leaf, in which case the lower part of the gate is inclosed, but rollers have not been adopted even for these extreme conditions.

The method of proportioning the girders is given in some detail in a subsequent section of this report.

Although the gates are of the horizontally-framed type, there must necessarily be a few verticals. What the action of these verticals is, and what effect they have upon the distribution of loads between the horizontals, is a very complicated problem, and considerable time has been given to its solution by several different methods.

For the purpose of an estimate, a large number of gates were designed in detail and their weights carefully computed. The law of variation of weight of gates for different widths and lifts of lock and depth of water on sill was discovered and some general equations giving the weight of gates for any width of opening, depth of water on sill, and lift of lock within limits were derived.

The foregoing is a brief statement of the work done and the results obtained.

Following will be found, under their proper heads, detailed discussions of the points mentioned above.

## CHOICE OF TYPE.

Besides the ordinary double-leaf mitering gate, which has been used so long and so exclusively that it has become the standard form, there are numerous forms of single-leaf gate. The differences between these various forms depend entirely upon the method by which they are moved into and out of place.

The sliding gate moves endwise into a recess in the side wall of the lock. The lifting gate moves vertically upward, and the plunging gate vertically downward. The single-leaf swinging gate revolves about a vertical axis at one of its ends, and the quadrant gate about a vertical axis in the center line of the lock at a distance from the gate of the half width of the lock. The tumble gate revolves about a horizontal axis at its lower edge. The bascule gate revolves about a horizontal axis at one of its lower corners, operating like the bridge of the same name.

All the above forms of gate have been proposed, and most of them have been used.

All forms of single-leaf gates possess in common the advantage of allowing a somewhat clearer and more definite analysis to be made of their stresses than does the mitering gate, and also the advantage of allowing simpler operating machinery.

For the work in hand the lifting gate could not be used on account of the masted vessels which will use the locks.

The plunging gate is practically untried and presents serious difficulties in the problem of keeping clean the pit into which it descends, and in most cases the masonry would cost more than for mitering gates. A roller bearing similar to that used in the Stoney sluice gate is usually introduced, which gives the gate the advantage of being moved rapidly and operated under much greater head of water than the mitering gate.

The sliding gate has been used in numerous cases in Europe and presents many advantages, chief of which is its ease of movement, as it is pulled endwise, thus offering less resistance to the water than it would if moved in any other direction. In a tidal lock it is especially adaptable, since it will withstand a pressure from either side. The gate may move on trucks or rollers on its bottom, or it may be suspended from above and run upon a fixed or a swing bridge.

The single-leaf swinging gate possesses the merit of reliability and of easily analyzed stresses, but is not economical, is slow of movement, requires much more power to operate it, and when used for a lower gate it reduces greatly the effective length of the lock.

The tumble gate has the advantage of easily analyzed stresses, simple masonry, and for low lifts it is quickly moved and is eco-

nomical of masonry, but it requires a pit in the bottom of the lock which is not easily cleaned. It is more particularly adapted for upper gates in the case of high-lift locks. When used as a lower gate it decreases too much the effective length of the lock. It has been used abroad and upon the Erie Canal in this country.

The advantages claimed for the quadrant gate are that it is quick of operation, and gives a maximum effective length of lock with minimum cost of masonry. On the other hand, it is as yet untried, and, considered with respect to its stresses, it is unscientific, since its reactions on the side walls are in a direction to increase the bending movement upon the horizontal girders, and, unlike all other forms of single-leaf gate, its reaction has a component normal to the side wall.

The bascule gate has been hardly more than suggested. It has no apparent advantages over the other forms of gate.

Designs and careful estimates were made of a single-leaf swinging gate, a single-leaf sliding gate, and a mitering gate, all for the same location, and it was found that they did not differ materially in weight.

The form of gate which would actually cost least will not be the same in different cases, but will vary with the width and depth of opening and lift of lock and with local conditions, but the difference of cost between any two of these forms of gate will not be great.

Speed of operation, reliability, and immunity from accident are more important considerations than first cost.

The mitering gate has stood the most rigid test, the test of time, and is practically the standard form of gate for locks. Its use shows no sign of abatement, and, as all the forms of single-leaf gates are more or less untried for large locks, it was deemed best to make the mitering gate the basis of estimate for the present work.

### MATERIAL.

The choice of material for the gates lay between wood and steel.

Wood has been used almost exclusively for small gates, and for large gates it has had its full share of favor. In this country, where timber is abundant, it has been used and has given excellent satisfaction, but like the wooden bridge, its use is on the decline, and the more recent large gates have been built of steel.

In England, however, although timber for gates has to be imported, it is still used quite as much as steel, even for the largest gates. A case in hand is the Manchester Ship Canal, which has all its gates built of green heart timber.

The advantages of timber for gates are its lightness when submerged, its ease of repair in case of accident, and in many localities its low first cost. On the other hand, the life of a timber gate is comparatively short. It begins usually to show weakness after from ten to fifteen years, involving repairs, and requiring to be renewed after from fifteen to twenty years.

Steel for gates is more in favor than wood in this country, and is preferred about equally in England, while on the Continent of Europe it is used exclusively.

When designed to admit of inspection and painting, steel gates are much more enduring. Some of the early examples show little rusting after thirty years.

The chance of accident is not believed to be great enough to warrant the use of wood on account of its ease of repair. In many of the proposed locks for the deep waterways the lift is so great that it would be almost impossible to provide the necessary strength in a wooden gate. For these reasons, and because steel is, structurally, a much better material than wood, steel gates have been designed for all the locks.[1]

### RISE OF SILL.

The principal functions of the two leaves of the mitering gate when closed is to form an arch, which takes the water pressure and transfers it to the side walls.

What the rise of this arch shall be is a question of some importance. The weight of the gate depends somewhat upon the rise of sill, but, as will be seen from the tables given under the head of "shape of horizontal frames," only to a slight extent. There are more important practical considerations which decide the question.

The less the rise of sill the longer will be the time required to open and close the gate, and the greater will be the thrust upon the masonry and the effect of any change in the length of the gate due to change of temperature. On the other hand, the greater the rise of sill the longer the gate and consequently the shorter the effective length of the lock, and if the gate be economically designed the deeper will be the gate and gate recesses.

The choice of rise of sill, then, becomes a compromise between the above advantages and disadvantages. Inasmuch as a rise of one-fifth the width of lock seems to best satisfy the practical considerations and also to require a somewhat lighter gate than any other, it has been used for all the gates designed.

### AIR CHAMBERS.

If the gate is not otherwise supported the pivot must carry the total weight of the gate less whatever flotation it may have, and, besides, both pivot and upper hinge sustain horizontal reactions of considerable magnitude.

Two methods have been followed to relieve the pivot upper hinge.

The first is to place under the gate a roller, which runs upon a track in the bottom of the lock and carries part of the weight of the gate. This device has been used with timber gates quite extensively, espe-

[1] Franzius. Der Wasserbau, p. 113 (Handbuch der Baukunde Abth III).

cially in England, but the custom is being discontinued. In order that the rollers shall work perfectly the axis of rotation of the gate must be perpendicular to the plane of the roller's track. Any inexactness in this plane or settling of the track may make the roller useless. Wearing of the roller bearing may do the same.

The second method of reducing the reactions at the upper-hinge pivot is to place a water-tight sheathing on both sides of the gate, forming an air chamber, which supports the gate by buoyancy. This method is quite generally used. It has, however, many serious disadvantages. As gates with sheathing on both sides have usually been built, their interiors have been very difficult to inspect, clean, and paint, on account of the too confined space for efficient work and especially the difficulty of ventilation while painting. The result has been that many inclosed gates have been left without painting of their interiors during their entire life, which was materially shortened thereby.

The gates sheathed on both sides are more expensive because the shop work and assembling of parts is more difficult; there are more joints to calk and the calking of joints must be done with greater care, and because the extra sheathing, especially when horizontal frames straight on the downstream side are used, adds weight and little or no strength.

The pivot and upper hinge must be made strong enough to sustain the reaction of the gate when it is swung in air at times when the lock is pumped out, therefore the pivot can not be made much smaller when double sheathing is used than when it is not.

It would seem that the gate with a single sheathing is preferable in every way, provided the pivot is not overstrained and its size is not impracticable.

All the gates designed, with the exception of a single case, have, as the drawings show, sheathing on one side only, leaving the interior open and allowing of inspection and painting at all times. This results in a very simple construction, which will cost little more than ordinary bridge work.

The single case for which it was thought necessary to provide additional buoyancy is that of the gates between the locks of the flights in the canal around Niagara Falls. Plate 74 shows a typical gate for this case. These gates withstand at times a head of water of 75 feet, and are unusually heavy in consequence. In these gates the sheathing on the downstream side is below the lower pool only, leaving all the upper part of the gate open.

In the chamber or hold thus formed a system of manholes is provided, which it is believed will partially overcome the principal disadvantage, except that of greater first cost, of the double-skin gate.

Four manholes are provided in all the horizontal frames in the air chamber. The manholes in the top and bottom of the chamber have

covers, the others are open. By removing the covers four shafts will be formed, in which it is expected a draft will be established, thus ventilating the interior and from which all parts of the chambers may be reached for cleaning and painting.

### QUOIN POST.

The function of the quoin post is fourfold. It must act as a column in carrying the weight of the gate; it must act as a girder transversely to the gate and also in the plane of the lines of thrust of the horizontal frames and distribute the pressure along the quoin; and withal it must furnish a satisfactory closure between the gate and wall.

The post as designed consists of a very thick web plate with four heavy flange angles. This forms the vertical girder acting transversely to the gate. To the flanges of this girder and lapping well upon the horizontal frames are riveted a heavy 36-inch plate on the upstream side and a 42-inch plate on the downstream side, which distribute the thrust of the horizontal frames.

It is deemed advisable to make the hollow quoin of stone and the bearing pieces of the quoin posts of wood, except in the heaviest gates, where metal is used. In most of the gates designed the thrust in the quoin is so great that the required bearing area demanded by the masonry is very large. A large bearing can be provided much more cheaply and satisfactorily by the use of wood than by steel for the bearing part of the post.

Wood is easily shaped. It adjusts itself to any unevenness or errors of workmanship and is more easily repaired or replaced in case of accident or wear.

As the drawings show, the wood is made cylindrical on the back to a radius of 15.5 inches, giving a projected width of bearing of 23 inches.

The axis of rotation has 1 inch eccentricity from the center of the cylinder. Thus the wood is relieved from bearing as soon as the gate begins to be opened. The eccentricity being small, there is very little chance for any foreign substance to lodge between the wood and masonry.

Some designers have maintained that the bearing surface should be flat instead of curved on account of the tendency of the curved bearing piece to split the quoin stones by its action as a wedge. This tendency may be entirely overcome by cutting the quoin stones so that the reactions at their backs will introduce a bending movement which shall nearly or quite balance that due to the thrust of the quoin post. Such a shape of quoin stones is shown on plate 68. Fortunately this is the most natural shape to give them.

From the consideration of the quoin post itself the cylindrical form has every advantage. Much greater width of bearing can be provided by its use than with the flat form, since the width of a flat bearing is limited by the consideration that the center of rotation must lie on the upstream side of a perpendicular to the bearing plane erected at

its upstream edge. The principal advantage, however, of the cylindrical bearing piece is the fact that the line of thrust must always pass through the center of curvature, while with a flat bearing piece the position of the line of thrust will always be in doubt, the only sure thing about it being that it has considerable variation, reducing the allowable average intensity of pressure upon the surface and causing an uncertainty and variation of the stresses in the horizontal frames.

In cases where the pressure per vertical inch of quoin does not exceed 9,000 pounds, it is proposed to use wood in the quoin post. As the width of bearing is 23 inches, the greatest intensity of pressure amounts to about 400 pounds per square inch between the wood and stone.

In some of the gates designed the thrust at the quoin passes this limit, as it was not thought practicable to make the timber bearing wider than 23 inches. A metal quoin and metal bearing pieces on the quoin post are used for these heavy pressures. This is shown in detail in figs. 7, 9, and 10, plate 74.

The post itself is the same as before, except the steel-casting bearing pieces.

This metal quoin is intended for use on all gates for the 80-foot locks, which withstand a head of water of more than 30 feet, and on gates for 60-foot locks, which withstand a head of more than 40 feet.

All the castings are of steel. No eccentricity is used, as in the case of wooden bearing pieces, the quoin and quoin post being in contact at all times. This eliminates all danger of foreign substances lodging between the bearing surfaces.

It may appear at first sight that this arrangement will cause a large frictional resistance in the quoin. These resistances will not be much greater without than with eccentricity in the quoin, since the horizontal thrust, due to the weight of the gate, must be taken care of either in the quoin itself or concentrated upon a bearing at the bottom of the gate. The lever arm of the frictional resistance of this bearing for the very heavy gates could not be made much shorter than the radius of the quoin, and, as friction is independent of area, little would be gained and much lost by providing an eccentric bearing.

The only gain would be the slight reduction of the horizontal thrust of the gate while turning, on account of the slightly lower position of its center of resistance and the fact that the smaller bearing would keep cleaner and have a somewhat lower coefficient of friction. However, even assuming a very high coefficient of friction, less than one-half horsepower will be required to do the work of overcoming friction in the heaviest gate.

### MITER POST.

The functions of the miter post are practically the same as those of the quoin post, the only difference being that it bears against

another similar post instead of against a hollow quoin and does not carry the weight of the gate. As designed, it is structurally the same, the only difference being in the shape of the bearing pieces, which are of the same material in the quoin and miter post in all gates.

Details of the posts having timber bearing pieces are shown on pl. 70, and those with steel bearing blocks are shown on plate 74. The drawings explain themselves without further description. Where timber is shown it is proposed to use white oak.

The practice in the past has been to use wood exclusively for the meeting faces of the gate. In a few of the more modern gates, however, steel is used. Wood has been preferred to steel because it makes a more water-tight joint on account of its more yielding nature. This is certainly true in cases where the thrust of the gate is not great. It is probable, however, that if the intensity of pressure between the steel bearing pieces be high and the parts carefully made a very good joint will result. In the present work the use of steel bearing blocks in some cases was imperative, since the thrusts are so great that a bearing 3 feet wide would be required if timber were used.

Considerable time has been given to the study of the position of the center of pressure at the meeting faces, since upon it depend quite largely the stresses in the horizontal frames.

The meeting faces may be made plane or curved. The former is the more usual shape and is entirely satisfactory when the thrusts are moderate enough to allow of a comparatively narrow bearing face being used; but when very wide bearing is required, plane meeting faces give trouble by "nipping" or meeting at their extreme edges. If the faces of the bearing pieces are planes, the most favorable condition is a uniform pressure over their entire surface.

This ideal condition can not be realized in practice, as it can only occur for one definite length of the gate leaves, and then only if the angle at which the meeting pieces are fitted is absolutely correct.

Since the length of the gate varies with the temperature and the stress to which the structure is subjected, and, furthermore, absolute exactness either in the shape of the gate or the fitting of the miter pieces is impossible, a strictly uniform pressure will never occur.

When gates are being closed and the two leaves approach each other, the bearing pieces will first meet on their extreme upstream or downstream edges, the faces making a very small angle with each other.

As the water pressure comes upon the gate the material compresses, and from being in contact at a line along the extreme edge they come in contact along a vertical strip extending from the edge of the meeting faces toward their middle, and in most cases bringing their entire surface into contact.

The position of the center of thrust depends upon the variation of intensity of pressure across this face.

Just what is the law of variation of intensity of pressure across the face of the timber bearing can not be told, as the wood will in most

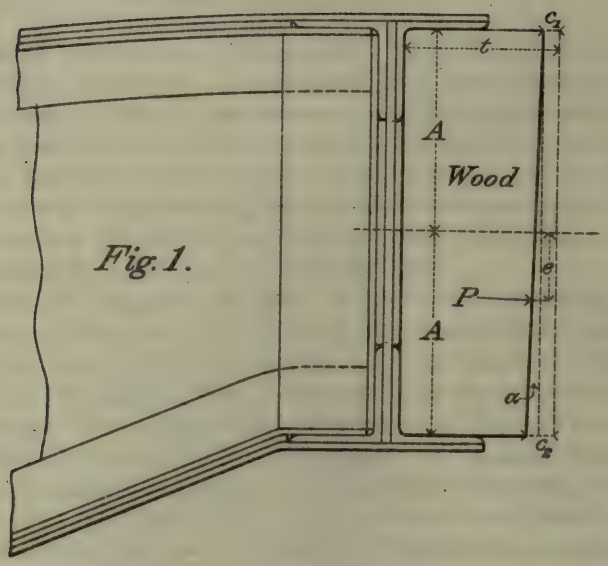


Fig. 1.

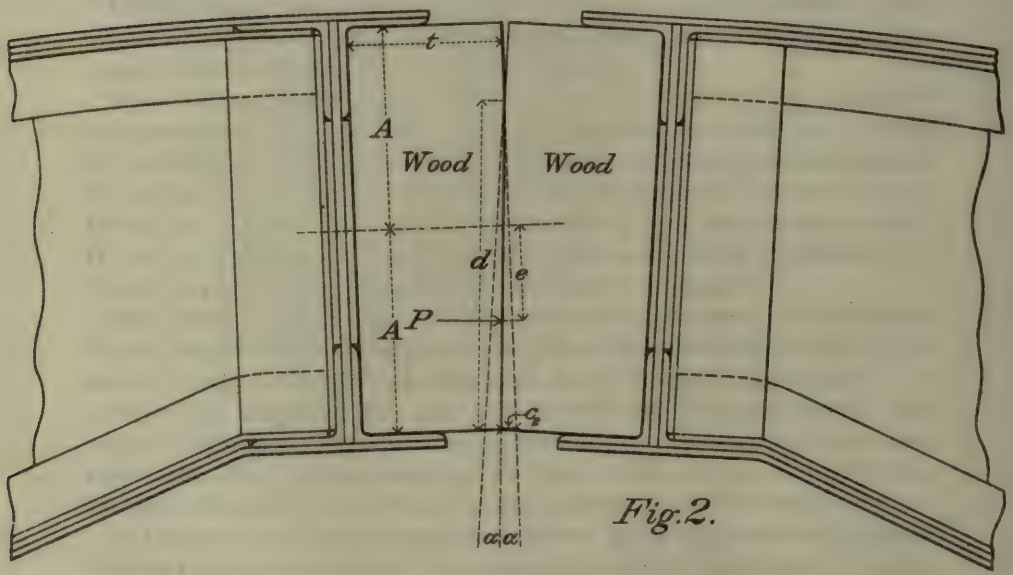


Fig. 2.

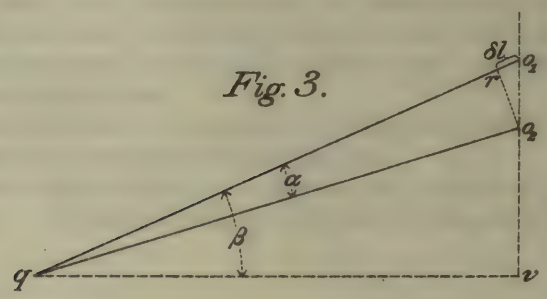


Fig. 3.

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cases be pressed beyond its elastic limit. As close an approximation as can be made is to assume that distortion is proportional to stress. In fig. 1 and fig. 3

Let $\alpha$=one-half the angle between the meeting faces,
$t$=thickness of the timber bearing,
$C_1$=compression of timber at its upper edge,
$C_2$=compression of timber at its lower edge,
$p_1$=intensity of pressure on timber at its upper edge,
$p_2$=intensity of pressure on timber at its lower edge,
A=one-half width of bearing face,
$E_2$=modulus of elasticity of timber,
P=thrust per vertical inch of miter,

Then, in fig. 1, which represents the case of contact over the entire face,

$$C_1=\frac{p_1 t}{E_2} \qquad C_2=\frac{p_2 t}{E_2}$$

or

$$C_2-C_1=\frac{t}{E_2}(p_2-p_1)$$

but

$$C_2-C_1=2\,A\tan\alpha$$

from which:

$$p_2-p_1=\frac{2\,A\,E_2\tan\alpha}{t}$$

again:

$$P=A\,(p_1+p_2)$$

Eliminating

$$p_2=\frac{P}{2A}+\frac{A\,E_2\tan\alpha}{t} \text{ and } p_1=\frac{P}{2\,A}-\frac{A\,E_2\tan\alpha}{t} \quad . \quad . \quad . \quad . \quad (1)$$

$$\text{Center of resistance from middle}=e=A-\frac{2\,A\,(2\,p_1+p_2)}{3\,(p_1+p_2)} \quad . \quad . \quad (2)$$

In fig. 2, which represents the case of partial contact:

$$C_2=d\tan\alpha$$

$$p_2=\frac{E_2\,C_2}{t}=\frac{E_2\,d\tan\alpha}{t}$$

But

$$p_2=\frac{2\,P}{d}$$

By elimination,

$$d=\sqrt{\frac{2\,P\,t}{E_2\tan\alpha}}$$

And,

$$p_2=\sqrt{\frac{2\,P\,E_2\tan\alpha}{t}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$e=A-\frac{d}{3}=A-\frac{1}{3}\sqrt{\frac{2\,P\,t}{E_2\tan\alpha}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Equations 1 and 2 apply when

$$2\,A \leqq \sqrt{\frac{2\,P\,t}{E_2 \tan \alpha}}$$

and equations 3 and 4 apply when

$$2\,A \geqq \sqrt{\frac{2\,P\,t}{E_2 \tan \alpha}}$$

The same results would be obtained in case of first contact at upstream edge.

The unknown factors in these equations are $\alpha$ and $E_2$.

The angle $\alpha$ may be said to be the result of error in workmanship or the result of a change in the length of the gate. To determine $\alpha$ we turn to fig. 3.

Let $qo_1$ represent a line of length L drawn from the hollow quoins to one edge of the bearing piece in the miter post.

Let $\beta$ = angle $o_1\,q.\,v.$

Let $o_2$ represent the new position of the edge of the bearing piece after change of length of gate.

Let $qr = qo_2$.

Let $\delta$ L = change in length of gate.

Let $\alpha$ = angular change in plane of bearing face due to change in length of gate.

Let $\delta_1$L = change of length of gate due to change of temperature.

Let $\delta_2$L = change in length of gate due to compression of steel.

Let $\delta_3$L = change in length of gate due to compression of wood.

Let K = the angle between the meeting faces due to error of workmanship, when the gates are first adjusted.

Let S = intensity of compression in the steel horizontal frames.

Let T = total thickness of timber in quoin and miter post.

Let $E_1$ = modulus of elasticity of steel.

Let P = thrust per vertical inch of miter post.

Then in circular measure:

$$\alpha = \pm \frac{\delta_1 L - \delta_2 L - \delta_3 L}{L \tan \beta} + K$$

$$= \pm \frac{\delta_1 L}{L \tan \beta} - \frac{\frac{SL}{E_1}}{L \tan \beta} - \frac{\frac{PT}{2AE_2}}{L \tan \beta} \pm K$$

$$= \pm \frac{\delta_1 L}{L \tan \beta} - \frac{S}{E_1 \tan \beta} - \frac{PT}{2AE_2 L \tan \beta} \pm K \quad . \quad . \quad . \qquad (7)$$

In this formula the first term represents that part of the angle caused by change of temperature, the second that caused by compression of steel, the third that caused by compression of the wood, and the fourth that caused by error of workmanship.

If the gate be supposed to be subjected to a range of temperature of from 32° to 112° F., then the greatest change from mean temperature will be 40° F., and $\delta_1 L$ will equal $.0000065 \times 40L = .00026L$.

$S = 9{,}000$ pounds per square inch for all frames,
$E_1 = 29000000$
$A = 11\frac{1}{2}$ inches
$L = 536$ inches in gate for 80-foot lock,
$T = 22$ inches.

As for K, let it be supposed that, owing to error of workmanship, the bearing blocks are set so that when the gates are closed they bear on one side, and the edges of the other side are separated by one-eighth inch. This would be a very noticeable error.

Then $\tan K = \pm \frac{L}{16 \times 2A} = \pm .0026$ for gate for 80-foot lock.

By substituting the constants in equation (7) the value of $\alpha$ is obtained in terms of $E_2$ and P.

As $\alpha$ is very small, we may put $\tan \alpha = \alpha$ and substitute in equations (1) and (2) or (3) and (4), which will give the intensity of pressure in the wood ($p_1$ and $p_2$) and the eccentricity of pressure ($e$) in terms of $E_2$ and P.

P varies from nearly 0, at the top of the gate, to a maximum not greater than 10,000 pounds per vertical inch of miter post at the bottom of the gate or below the lower pool.

$E_2$ is quite largely a function of the condition of the timber as regards moisture. It ranges from 20,000 to 200,000 for white oak. As low values as 20,000 were obtained from measurements of the compression of the timber in the miter posts of the Poe Lock at Sault Sainte Marie. These measurements gave no values higher than 40,000.

The timber in these gates had been in use about three years and was well saturated. As high values as 200,000 have been obtained from laboratory experiments upon well-seasoned wood.

Substituting these two extreme values of $E_2$ in connection with various values of P in the proper equations, either 1 and 2 or 3 and 4 as determined by equations (5) and (6), the following values $e$ and $p_2$ are obtained:

$E_2 = 20{,}000$.

| P | $e$ | $p_2$ | P | $e$ | $p_2$ |
|---|---|---|---|---|---|
| 1,000 | 6.9 inches. | 130 pounds per square inch. | 6,000 | 2.0 inches. | 377 pounds per square inch. |
| 2,000 | 4.9 inches. | 188 pounds per square inch. | 7,000 | 1.8 inches | 424 pounds per square inch. |
| 3,000 | 3.6 inches | 237 pounds per square inch. | 8,000 | 1.6 inches | 469 pounds per square inch. |
| 4,000 | 2.8 inches | 283 pounds per square inch. | 9,000 | 1.5 inches. | 517 pounds per square inch. |
| 5,000 | 2.3 inches | 330 pounds per square inch. | 10,000 | 1.4 inches. | 564 pounds per square inch. |

In the same way for $E_2 = 200{,}000$:

| P | $e$ | $p_2$ |
|---|---|---|
| 1,000 | 10.3 inches. | 400 pounds per square inch. |
| 3,000 | 9.2 inches. | 702 pounds per square inch. |
| 6,000 | 8.0 inches. | 1,000 pounds per square inch. |
| 10,000 | 6.9 inches. | 1,300 pounds per square inch. |

The first table in which $E_2 = 20{,}000$ probably represents the most favorable condition, so far as $e$ is concerned, that can be expected.

Under these conditions the maximum distance of the center of pressure from the center of the bearing piece is, as the table shows, 7 inches at the top of the gate, gradually decreasing to less than 2 inches below the lower pool.

It must be remembered that, so far as the steel horizontal frames are concerned, great variation of the center of pressure in the upper part of the gate is quite as objectionable as in the lower part, since, although the intensity of pressure on the wood is not so great, the horizontal frames, being spaced farther apart, have as high a stress as those below.

The excessive values of $e$ in the upper part of the gate may be eliminated by making the bearing face vary in width from a minimum of, say, 6 inches at the top of the gate to the full width at the surface of the lower pool. Fig. 4 shows the plan and face elevation of such a bearing piece; $a$, $b$, $c$, $e$, $f$, $h$ represents a top section and $a$, $b$, $d$, $g$ a bottom section.

Under less favorable conditions when the wood is dry, as seen in the second table, in which $E = 200{,}000$, the distance of the center of pressure from the center of the bearing face may vary from 10.3 inches at the top of a 24-inch bearing piece to 7 inches at the bottom.

If the designer is convinced that the bearing blocks will be thoroughly saturated at all times, and if he will proportion them so that the pressure per vertical inch of miter, divided by the width of bearing face in inches, shall be about 400, thus giving to them the shape indicated above, he may use bearing blocks with plane meeting faces with little fear that the center of pressure will be more than, say, a tenth the width of face from its center. If he is not sure of this, he must make whatever assumptions seem to him reasonable.

No formula can give exact values of $e$, since the condition of the timber changes from time to time, becoming softer with age and saturation, and the foregoing analysis is not given for the purpose of obtaining exact values, but to assist in making more intelligent assumptions.

The analysis is of value in showing what the shape of the bearing pieces should be and indicating what effect upon the strains in the gate the use of wood in the quoin and miter post has.

*Fig. 4.*

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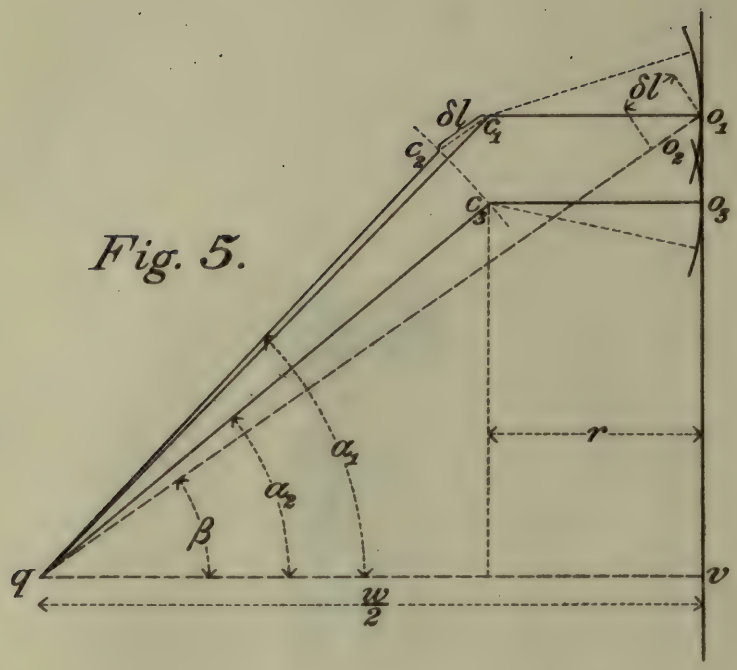



Fig. 5.

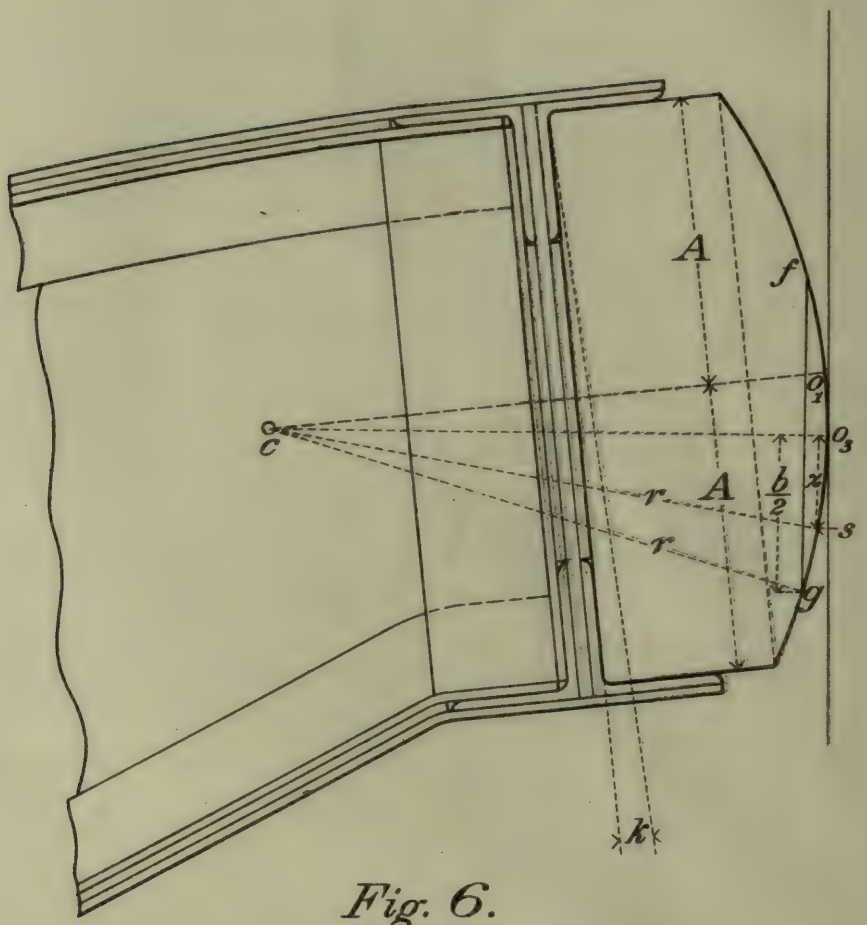



Fig. 6.

The deduction from the above analysis is that with a plane bearing face 24 inches wide there is a wide range (from 0 to ± 8 or 9 inches) of eccentricity possible, depending upon the condition of the wood, and that the uncertainty is so great that it is very desirable to eliminate it if possible by the use of another shape of bearing block.

As the following analysis shows, by giving the bearing blocks a cylindrical form of large radius, there will be much greater certainty that the range of the center of pressure will be confined to narrower limits.

As before, the position of the center of pressure depends upon change in the length of the gate and accuracy of workmanship.

In Fig. 5,

Let $\delta L$ = change in length of gate.

Let $q$ be the back of hollow quoin.

Let $\beta$ = angle $0_1 q c$.

Let $r$ = radius of the bearing pieces.

Let $C_1$ be the center of the curve of the face of the bearing piece before change of length of gate.

Let $C_3$ be the center of the curve of the face of the bearing piece after change of length of gate.

Let $w$ = distance between hollow quoins.

Let $0_1$ represent the point at which the gates will touch before change of length. This is supposed to be the middle of the face of the bearing block.

Let $0_3$ represent the point at which the gates will touch after change of length.

Let $e$ = distance from center of bearing block to center of pressure.

Let L = length of gate = $q0_1$.

Suppose that a change of length $\delta L$ takes place without revolution of the gate, and $0_1$ passes to a position $0_2$, and $C_1$ passes to a position $C_2$. Then $C_1C_2$ will be parallel to $q0_4$.

Suppose, then, that revolution of the gate takes place until the gates meet at $0_3$,

Then

$$\tan \alpha_1 = \frac{\frac{1}{2} w \tan \beta - \delta L \sin \beta}{\frac{1}{2} w - r - \delta L \cos \beta}$$

$$\cos \alpha_2 = \frac{\frac{1}{2} w - r}{\sqrt{(\frac{1}{2} w \tan \beta - \delta L \sin \beta)^2 + (\frac{1}{2} w - r - \delta L \cos \beta)^2}}$$

$$e = r \tan (\alpha_1 - \alpha_2) \pm r \tan K. \quad . \quad . \quad . \quad . \quad . \quad (8)$$

$$\delta L = \pm .0000065 t L - \frac{sL}{E_1} - \frac{TP}{2AE_2} \quad . \quad . \quad . \quad . \quad . \quad (9)$$

In which:

$t$ = one-half extreme range of temperature in degrees Fahrenheit.
$E_1$ = modulus of elasticity of steel.
$E_2$ = modulus of elasticity of wood in quoin and miter post.
T = total thickness of timber in quoin and miter post.
P = thrust per vertical inch of miter post.
A = half width of wood in quoin and miter post.
L = length of gate.
$s$ = intensity of compression in horizontal frames.

The first term in the value of $\delta L$ represents the change due to change of temperature; the second, the change due to the compression of the steel, and the third, the change due to the compression of the wood.

It is evident that $\delta L$ will be greatest when P is greatest and $E_2$ is least.

If the range of temperature be from 32° to 112° F., then

$t$ = 40.
L = 536 in gate for 80-foot lock.
$E_1$ = 29,000,000.
P = from 0 to 10,000.
$E_2$ = from 20,000 to 200,000.
$\frac{1}{2}w$ = 498 inches in 80-foot lock.
$\beta$ = arc tan .4.
K = an angle produced by an error of workmanship in making one side of the bearing piece thicker than the other.

Supposing that one side of the bearing block be made one-sixteenth inch thicker than the other, K will be,

$$\text{arc tan } \frac{1}{16 \times 24} = 0.0026.$$

Putting $r = 300$ inches and substituting the above value in the proper equations, using $E_2 = 20{,}000$ and $P = 10{,}000$, and using all minus signs, we get for a maximum $e = -1.8$ inches. This is measured on the upstream side of the center of the bearing block. The value of $e$ for the downstream side, obtained by making P small and $E_2$ large and making all signs plus, is + 0.7 inch.

By comparing this maximum with 9 or 10 inches, found for bearing blocks with plane faces, it would seem that without doubt the curved bearing is the better one to use.

As the drawings show, all the bearing blocks have been made 8 inches thick and cylindrical to a radius of 300 inches. The practice of those in charge of locks bears out the wisdom of this. It is their custom, when the gates give trouble by nipping, to slightly round the faces of the bearing blocks, which expedient has been found to remove the trouble.

To determine the intensity of pressure upon the timber, let fig. 6 represent a bearing piece compressed to any line, as $f\,g$.

Let $s$ be any point on the compressed surface.

Let $x$ = its distance from $c\ O_3$.

Let $O_3$ be the point of first contact.

Let P = pressure per vertical inch of miter post.

Let $p$ = intensity of pressure at $s$.

Let $r$ = radius of face-bearing piece.

Let $b$ = the breadth of the surface in contact.

Let $t$ = thickness of bearing piece (if $r$ is large, $t$ may be taken as uniform).

Let $d$ = amount of compression at $s$.

Let $E_2$ = modulus of elasticity for wood.

Then

$$d = \sqrt{r^2 - x^2} - \sqrt{r^2 - \tfrac{1}{4}b^2};\ \text{also}\ d = \frac{tp}{E_2}$$

From which

$$p = \frac{E_2}{t}\left(\sqrt{r^2 - x^2} - \sqrt{r^2 - \frac{b^2}{4}}\right)$$

$$P = \frac{2E_2}{t}\int_0^{\frac{b}{2}}\left(\sqrt{r^2 - x^2} - \sqrt{r^2 - \frac{b^2}{4}}\right)dx$$

$$= \frac{E_2}{t}\left(r^2 \sin^{-1}\frac{b}{2r} - \frac{b}{2}\sqrt{r^2 - \frac{b^2}{4}}\right) \quad . \quad . \quad . \quad . \quad . \quad (10)$$

$p$ is a maximum at point $x = 0$

Then

$$p\,(\max) = \frac{E_2}{t}\left(r - \sqrt{r^2 - \frac{b^2}{4}}\right) \quad . \quad . \quad . \quad . \quad . \quad (11)$$

By using the maximum value of 10,000 pounds for P and making $r = 300$ inches and $t = 8$ inches it was found from equations 10 and 11 that the maximum value of $p$ for $E_2 = 20{,}000$ is 830 pounds per square inch, and for $E_2 = 200{,}000$ it is 1,500 pounds per square inch.

## STEEL BEARING PIECES.

Very much more favorable conditions as regards eccentricity of pressure prevail when steel bearing blocks are used in the quoin and miter posts. Very little uncertainty exists in regard to the position of the center of pressure, and it is quite certain that its variation will be small.

The steel meeting faces are curved to a radius of 300 inches. The last term of equation (9) vanishes, leaving

$$\delta L = + 0.0000065\ t\ L - \frac{s\,L}{E_1}$$

All the factors of this equation are definite and well known, and $\delta L$ is small under the worst conditions of change of temperature which are likely to exist. Assuming the same error of workmanship and substituting as before in equations (8) and (9) we get $e_1 = 1.2$ inches and $e_2 = .78$ inch. (See fig. 8 for $e_1$ and $e_2$ for the worst case of the gate for 80-foot lock.)

It is believed that this represents about the maximum range of the position of the center of pressure when metal bearing blocks curved to a radius of 300 inches are used.

It is impossible to tell what the intensity of pressure upon these steel meeting faces will be. The best that can be done is to use one of the numerous empirical formulæ for the safe load upon rollers.

Substituting in the formula $f = 1{,}700\sqrt{R}$, in which R = radius of meeting face and $f$ = allowable safe load per lineal inch of roller, we get $f = 29{,}400$ pounds, which is a greater load than will be developed in any of the proposed gates.

## FRAMING.

Since the two leaves of the gate form an arch which receives the horizontal load of the water pressure and transmits it to the side walls, it necessarily follows that the principal members of the gate must be horizontal frames extending from miter to quoin post. These horizontals may be placed so close together that the sheathing is able to deliver the water pressure directly to them, or they may be placed farther apart and vertical girders employed to take the pressure from the sheathing and deliver it to them.

These two arrangements divide gates into two classes, known as the horizontal and vertical types, the relative merits of which have been made the subject of much discussion.

An extreme case of vertical framing is the use of but one horizontal, and that at the top of the gate, allowing the lower end of the verticals to bear against the sill. This has the advantage of allowing a very clear analysis of the stresses in the verticals and making the sill do much of the work that would otherwise be done by the horizontals. This form of gate may be economical under small heads of water and in gates that have much greater length than height. A difficulty arises, however, in providing a satisfactory detail at the miter and quoin posts.

Between this extreme case and the purely horizontally framed type there is the case of relatively few horizontals with intermediate verticals. A satisfactory detail at the miter is possible with this arrangement, and it has a field in which it may be used with economy. This field includes cases of very low lift of lock in which the pressures are small. This type may be used with economy for upper and lower gates for 80-foot locks having lifts less than 10 or 12 feet and for 60-foot locks having lifts less than 8 or 10 feet.

These cases are very rare, however, in the locks for the proposed deep waterway, and all the designs are of purely horizontal type of framing.

HORIZONTAL FRAMES.

One of the questions in gate design most frequently discussed is, What shall be the shape of the gate in plan, i. e., what is the proper form of the horizontal frames?

A circular arch form is advocated quite generally, on the ground that for the same strength it is lighter and is therefore cheaper. A sort of gothic arch is preferred by some engineers, and still others advocate the so-called girder form which is straight on the downstream side and any desirable shape on the other. The advocates of this latter form maintain that it has many inherent advantages over any other and that when properly designed its weight will be but little greater than the arch form, and that, owing to its greater simplicity, its low cost of construction will make it as cheap or cheaper.

The considerations which should decide the form of horizontal frame are the following:

It is very desirable that the gate recesses in the lock walls should be as shallow as possible. This is a decided point in favor of the so-called girder shape.

It is also considered desirable that when the gates are open and in their recesses they should continue the line of the wall; in other words, be straight on the downstream side.

The gate should be as stiff and rigid as possible against unavoidable accidental blows and rough usage to which it will be subjected. The arch, being comparatively thin, is notably weak in this respect.

For the work in hand it is especially desirable, for reasons which have already been discussed, to use a single skin gate. Consequently it is desirable that the gate should be straight on the downstream side, to allow of diagonal bracing.

Lastly, there is the question of economy. In the face of the above disadvantages, however, it would seem that the arch form must show very much greater economy in order to be preferred to the gate straight on the downstream side.

The cost of a structure is made up of two elements—cost of material and cost of workmanship.

The cost of material depends upon conditions over which the designer has no control. The cost of workmanship depends quite largely upon the character of the design. The amount of material which may be used to save cost of workmanship depends upon the relative cost of the two. This relation has continually changed, and any deductions based upon it at one time will not necessarily apply at another.

As the cost of material decreases, the greater will become the relative economy of simple structures. In general, the so-called girder

shape will be simpler than the arch and make the gate cost less per pound.

If the line connecting the centers of gravity of different sections of a horizontal frame coincides with the line of thrust, then it will be a perfect arch without transverse stress. If this arch has a rise conducive to economy, there is little doubt that so long as this ideal condition of exact coincidence of center of thrust and center of gravity exists the minimum amount of material will be required for the frame.

The circular arch can be readily made to fit this condition for one position of the line of thrust, but the line of thrust must pass through the center of pressure at the miter, and, as has been seen in the study of the miter, the position of this center of pressure varies between rather wide limits, depending upon the construction of the bearing blocks. Any deviation of the line of thrust from the line of centers of gravity introduces cross bending in the arch, which is not well shaped to withstand it, thus requiring a certain additional amount of material to resist bending.

The frame, straight on the downstream side, though usually heavier when proportioned for a single position of the line of thrust, requires, on account of its greater depth, a smaller addition of material to cover the effect of bending.

It would seem that the arch form of horizontal frame will be the lightest if the miter can be so arranged that there will be no variation in the position of the center of pressure, and that it shows less and less economy as the variation increases until, if the eccentricity becomes great enough, the girder shape will be the lighter, always supposing that it has the greater depth, which in general will be the case. This conclusion is borne out by the investigation which follows.

Besides the question of the relative economy of the two general forms of horizontal frame, there is the question of the proper rise of sill and depth for each.

It was recognized that a mere mathematical analysis is not sufficient to determine the form most economical of material, since in practice with the ordinary forms of rolled steel it is not possible to make a theoretically perfect distribution of material. The importance of the question and the magnitude of the work in hand seemed to warrant the making of a somewhat lengthy investigation of the questions involved.

Three investigations were carried out. The first involved the designing and determining the weight of horizontal frames of different shapes for over a thousand different gates. This included 10 shapes of frame for upper and lower gates for 60 and 70 foot locks of lifts varying from 30 to 50 feet and rises of sill of one-fourth, one-fifth, and one-sixth the span. These weights of the horizontal frames are tabulated on plates 75 and 76 and are plotted on plate 77.

By the results of this investigation it was hoped to be able to answer

the following questions: For a 60 and 70 foot lock, what rise of sill and what shape of gate will give the lightest gate if double skin be used, or if single skin be used, or if the skin be assumed not to act as part of the frame in resisting water pressure.

From the diagrams it is seen that the arches are somewhat lighter for all lifts. It is also seen that the lightest gate of each of the three cases of rise of sill do not differ greatly in weight. In other words, within the limits of the investigation the rise of sill does not cut much of a figure.

The saving in material by the use of the arch is in all cases less than 10 per cent of the weight of a gate, which is believed to be insufficient to warrant its adoption in the face of the great practical advantages of the gate straight on the downstream side. It is thought that difficulties in the construction of the arch will make the unit price enough higher to make up for the small difference in weight.

The second investigation was less general. It included the determination of the most economical shape of horizontal frame for the gates of an 80-foot lock only. It was also decided that a rise of sill of one-fifth the width of the lock is most desirable for practical reasons, and that a certain amount of the sheathing should be considered as acting as a part of the horizontal. This reduced the length of the investigation very considerably.

Four girder shapes with depths at the middle of 4, 4½, 5, and 5½ feet, and two arch forms 3½ feet deep at their middle, were designed for the same heads and under the supposition that the range of the center of pressure at the miter will be 8 inches each side of the middle of the bearing blocks. The weights were compared, and it was found that the girder shape 5 feet deep at the middle was the lightest. This was considered a very good shape to satisfy the practical considerations mentioned above, although later, in the actual design of the gates, as will be seen by reference to the drawings, the width at the middle was reduced to 4½ feet in order to keep the gate recesses shallow, there being little loss of economy by so doing.

The third investigation was made to discover the influence which the variation of the position of the center of pressure at the miter has upon the determination of the most economical shape of horizontal frame.

In this study, single and double skin gates for 60 and 80 foot locks of several different lifts with values of $e$ (see figs. 2 and 3) varying from 0 to $\pm$ 8 inches were designed and estimates of weights made. This investigation included two shapes—a desirable girder form and the circular arch somewhat thicker in the middle than at the ends.

As a preliminary, the weight of a single horizontal frame of each of the two shapes, figs. 1 and 2, plate 78, loaded to 6,500 pounds per linear foot was found for a single and double skin gate with value of $e$ varying by 2 inches from 0 to $\pm$ 8 inches. The weights found are platted in the first diagram, plate 78.

This diagram shows that the weight varies practically uniformly with $e$; that is, the curves are straight lines and need only two points to determine them. It also shows that for this case the arch is the lighter if no bending be introduced, and that as $e$ becomes greater it shows less and less economy until at $e = 8$ inches it is practically no lighter for single-skin gate, and that if $e$ were still more increased it would be heavier than the girder.

The investigation was then continued and made to include, instead of one girder, the entire single and double skin gates for 60 and 80 foot locks, of several different lifts and shapes of horizontal frames shown in figs. 1, 2, 3, 4, plate 78. The horizontal frames were proportioned by the most rigid and exact method. (See method given under the head of "Proportioning of horizontal frames.") They were designed for $e = 0$ and $e = 8$ inches only, it being evident from the preliminary work that these may be platted and the points connected by a straight line. Diagrams representing the results obtained are shown on plate 78. In these diagrams abscissas represent eccentricities and ordinates represent weights of lower gate.

The deductions from the results obtained are:

First. If the gate be designed for small variation of center of pressure at the miter, the arch will be the lightest form for the same strength.

Second. The economy of the arch becomes less if $e$ be increased until if $e$ be taken great enough the girder form will be the lighter, always supposing that it is the deeper, which in general will be the case.

Just how great $e$ will have to be for the arch to be the heavier will depend upon width and lift of lock and relation of the thickness of the two forms of gate. In other words, as $e$ increases a point will be reached at which the thicker gate, whether it is the arch or girder, will be the lighter for the same strength.

Third. The arch form of horizontal frames gives relatively greater economy in double-skin than in single-skin gates.

Fourth. In single-skin gates for 60 or 80 foot locks, if the variation of the center of pressure at the miter be 4 or 5 inches more on each side of the center of the bearing, the economy in material shown by the arch is certainly not great enough to overbalance the great inherent advantages of the gate straight on the downstream side and probably not great enough to make it the cheaper form in the present condition of the steel market.

A careful weighing of all the practical considerations and the conclusions of the investigations in regard to economy resulted in the adoption of the shape of horizontal frame shown on plates 70, 71, 72, 73, and 74.

It will be noticed that the frame is perfectly symmetrical about its middle.

It is so shaped that the centers of the bearing faces, both in the quoin and miter posts, are placed well downstream. A line joining the

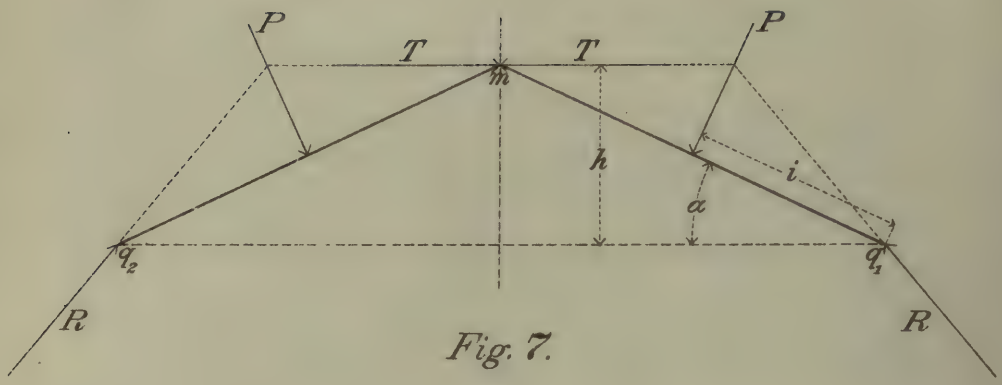



*Fig. 7.*

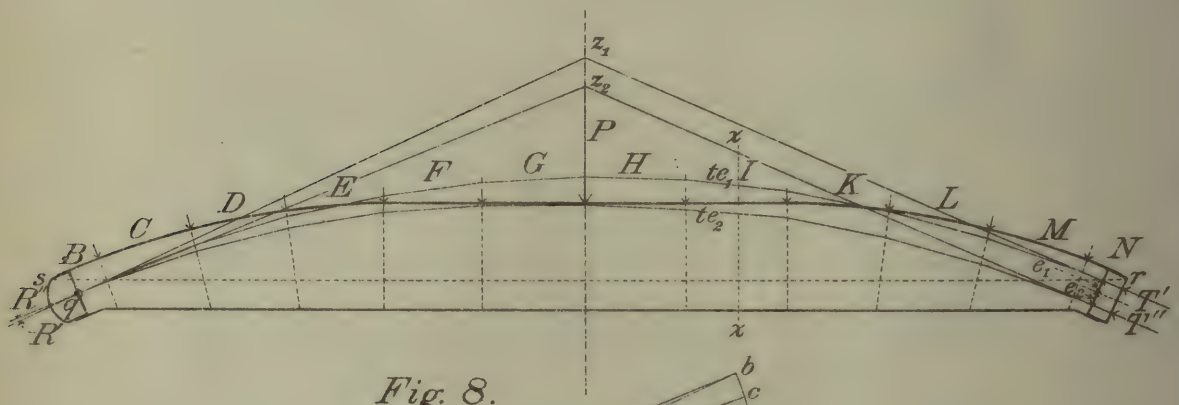
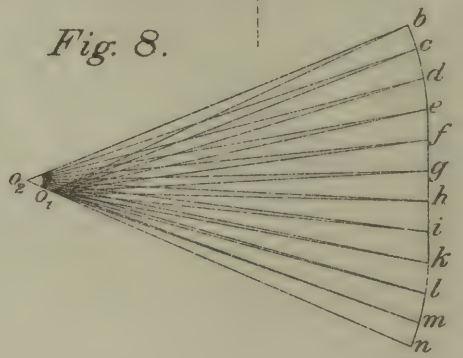



*Fig. 8.*

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centers of the faces of the bearing pieces in quoin and miter lies only $5\frac{1}{2}$ inches away from the outside edge of the downstream flange—a very favorable arrangement.

It is believed that the frames have been so designed that the shop-work and erection will be very easily and cheaply done.

### PROPORTIONING OF HORIZONTAL FRAMES.

The direct load due to water pressure on any part of the gate is very easily found, since the intensity of pressure at any point is directly proportional to the head of water at that point.

In fig. 12, if A O is a vertical section of a gate with stages of water as indicated, the ordinates at any point of the line $a\ b\ c$ will be proportional to the water pressure at that point.

The loads on the horizontal frames are not the same as the external loads of water pressure, for the reason that the vertical stiffness of the gate causes a redistribution of the loads.

The entire subject of the effect of vertical stiffness of the gate is discussed in a subsequent paragraph.

The principal effect of this redistribution is to throw an increase of load into the upper part of the gate.

The strength of the horizontal frames is made proportional to the distances between the lines $a\ f$ and $d\ e\ b\ c$. In other words, the horizontals, which withstand a head of more than about 20 feet, are proportioned for the direct load of water pressure which will come upon them, and the upper 20 feet of the gate is made of uniform strength, capable of withstanding a head of 20 feet.

The increase of strength in the upper part of the gate is on account of the effect of the vertical stiffness and because it seemed best not to place the horizontal frames farther apart than they are and to use no lighter than three-eighths inch metal in their construction.

A combination of a graphical and an analytical method was used to determine the stresses and proportion the frames. An equilibrium polygon, or line of thrust, was constructed graphically, and from the position and magnitude of the thrust at any point the required flange section was given directly by a formula.

In fig. 7—

Let $q_1$ and $q_2$ be the centers of the hollow quoins.

Let $m$ be the position of the center of pressure at the miter.

Let P be the resultant of the water pressure acting upon one frame.

Let R be the reactions at the hollow quoins.

Let T be the thrust at the miter.

$e_1$ and $e_2$ are, as before, the distance from the center of the bearing to the center of pressure.

Then, if the two leaves of the gate be exactly alike, the direction of the thrust T will be parallel to $q_1\ q_2$ and

$$T = P\frac{i}{h} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

Then, for equilibrium, the lines P, T, and R must intersect in a point, from which consideration both the magnitude and direction of R may be determined. If P be perpendicular to $q\ m$ at its middle, then R = T and its direction makes an angle $2\alpha$ with a normal to the wall. Let fig. 8 represent a horizontal frame acted upon by a load $p$ per unit of length.

Then P, the resultant pressure upon the frame, will have a position, as in fig. 8, perpendicular to $s\ r$ at its middle and $P = p\ s\ r$.

The extreme positions of the center of pressure at the miter having been previously decided upon at these extreme points, T′ and T″ may be drawn, their directions being known, as in fig. 7. If these lines be extended to cut the line of P in points $z_1$ and $z_2$, then $q\ z_1$ and $q\ z_2$ will give the directions of the reactions at the center of the hollow quoin.

If B C, C D, etc., represent the pressures acting upon a frame, a force diagram may be constructed in the usual way, as in fig. 8.

The reactions at the hollow quoin are $b\ 0_1$ and $b\ 0_2$. The thrusts at the miter are, $n\ 0_1$ and $n\ 0_2$. These latter values may be checked by formula (12).

The equilibrium polygons may now be constructed, which will give for any section the position of the center of the thrusts, the magnitude of which may be found from the force diagram.

The force diagram $b, c \ldots m, n$ is a reproduction to a smaller scale of the upstream side of the frame, since each of its elements, representing water pressure, is normal to and proportional to the length of each element of the upstream side of the gate.

Only one stress diagram need be constructed for all frames of the same shape and having the same values of $e_1$ and $e_2$.

Suppose that the force diagram be constructed for all frames of the same shape and having the same values of a load of 1 pound per linear foot of frame, then if $te_1$ and $te_2$ be the thrusts at any section as XX for a load of 1 pound per linear foot of frame, $nte_1$ and $nte_2$ will be the thrusts for a loading of $n$ pounds per linear foot.

If $h$ be the effective head of water acting upon any horizontal frame and $b$ be the sum of the half distances to each adjacent frame, we may put

$$n = 62.5\ b\ h$$

$$\text{or } Te_1 = 62.5\ b\ h\ t\ e_1 \text{ and } Te_2 = 62.5\ b\ h\ t\ e_2$$

In which $Te_1$ and $Te_2$ are thrusts at any section of any frame.

By inspection it is seen that the upper flange will be most strained near its middle and when the line of thrust is in its upper position, and that the lower flange will be subject to reversal of stress, maximum tension occurring at its middle and maximum compression near its ends. In all the gates designed the maximum tension in the lower flanges is very small.

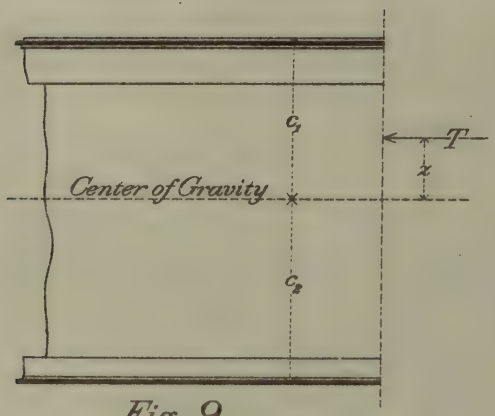


*Fig. 9.*

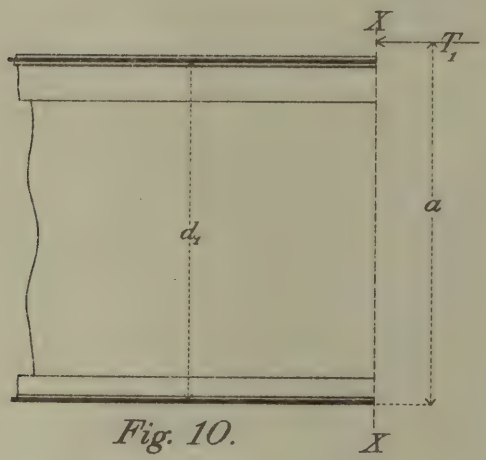


*Fig. 10.*

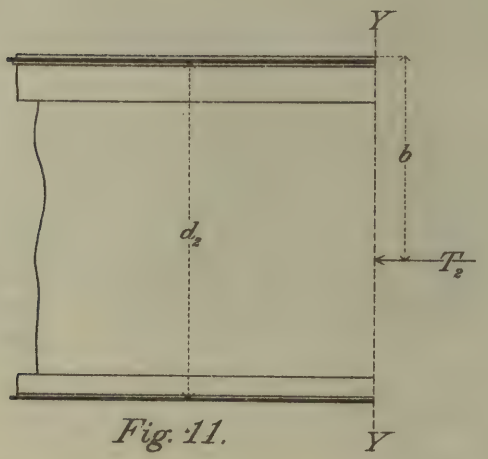


*Fig. 11.*

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By reference to plates 70 to 74 it is seen that the lower flanges are heavily reenforced near their ends, and a few trials show that the critical section for the lower flange is Y Y, taken near the end of the reenforcing plates.

In fig. 9,

Let T be the thrust at any section.

Let $x$ be the distance from the center of gravity of the section to the center of thrust.

Let $C_1$ and $C_2$ be the distance from the edges to the center of gravity of the section.

Let $f_1$ = stress in upper edge, and

Let $f_2$ = stress in lower edge.

Let A be the area of the section.

Let I be the moment of inertia of the section.

Then,

$$f_1 = \frac{T}{A} + \frac{xC_1T}{I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

and

$$f_2 = \frac{T}{A} - \frac{xC_2T}{I} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

By assuming various flange sections and making a series of trials by the use of the above formula, flange sections may be found which will give satisfactory values for $f_1$ and $f_2$.

This method was found very tedious, as the flanges must satisfy the conditions at each of the two different sections, and especially in the investigations of the relative economy of different shapes. In these cases it was necessary to so proportion the frames that the maximum stress should be practically the same in the various cases compared; otherwise the comparison of weights would be of little value.

A more direct method was sought, with the result that the following formulæ were developed:

Let X X, fig. 10, be the critical section for the upper flange.

Let Y Y, fig. 11, be the critical section for the lower flange.

Let $T_1$ be the thrust acting at section X X.

Let $a$ be its greatest distance from the lower edge of the web.

Let $d_1$ be the depth of the frame at X X.

Let $T_2$ be the thrust acting at Y Y.

Let $b$ be its greatest distance from the upper edge of the web.

Let $d_2$ be the depth of the frame at Y Y.

Let $F_1$ be the area of the upper flange.

Let $F_2$ be the area of the lower flange.

Let $f_1$ be the stress in the upper flange at section X X.

Let $f_3$ be the stress in the lower flange at section X X.

Let $f_4$ be the stress in the upper flange at section Y Y.

Let $f_2$ be the stress in the lower flange at section Y Y.

Then in section X X, if it be assumed that the stress varies uniformly from $f_3$ at the lower edge to $f_1$ at the upper edge, the resistance of the web will be $\frac{d_1 t (f_1 + f_3)}{2}$ and the distance of its center of resistance from its lower edge will be $\frac{d_1 (2 f_1 + f_3)}{3 (f_1 + f_3)}$.

If we assume the center of gravity of the flanges to be at the edge of the web, the resistance of flanges may be taken to be $F_1 f_1$ and $F_2 f_3$, and by taking moments above the lower edge we have:

$$a T_1 = d_1 f_1 F_1 + \frac{d_1^2 t (2 f_1 + f_3)}{6} \quad . \quad . \quad . \quad . \quad . \quad (15)$$

Also for equilibrium:

$$T_1 = f_1 F_1 + f_3 F_2 + \frac{d_1 t (f_1 + f_3)}{2} \quad . \quad . \quad . \quad . \quad . \quad (16)$$

Making these two equations simultaneous, any two of its factors may be found, the rest being known.

In like manner, equations for Sections Y Y, fig. 11, may be formed. They are:

$$b T_2 = d_2 f_2 F_2 + \frac{d_2^2 t (2 f_2 + f_1)}{6} \quad . \quad . \quad . \quad . \quad . \quad (17)$$

$$T_2 = f_2 F_2 + F_1 f_4 + \frac{d_2 t (f_2 + f_4)}{2} \quad . \quad . \quad . \quad . \quad . \quad (18)$$

The conditions of economical proportioning are that $F_1$ and $F_2$ shall be such that $f_1$ at Section X X shall have the value of the maximum allowable intensity of pressure when $T_{e1}$ is acting, and $f_2$ at Section Y Y shall have the maximum allowable intensity of compression when $T_{e2}$ is acting.

Eliminating $f_3$ from equations 15 and 16, we have:

$$F_1 = \frac{\frac{3aT_1}{d_1} - \frac{f_1 t d_1}{2} - T_1 + \frac{6aT_1}{d_1^2 t} - 2f_1 F_2}{2f_1 + \frac{6f_1 F_1}{d_1 t}} \quad . \quad . \quad . \quad . \quad . \quad (19)$$

Eliminating $f_4$ from equations 17 and 18, we have:

$$F_1 = \frac{\frac{3bT_2}{d_2} - \frac{d_2 t f_2}{2} - T_2 - 2f_2 F_2}{2f_2 - \frac{6bT_2}{d_2^2 t} + \frac{6f_2 F_2}{d_2 t}} \quad . \quad . \quad . \quad . \quad . \quad (20)$$

If the flanges do not change in section between X X and Y Y, then equations (19) and (20) are simultaneous in $F_1$ and $F_2$.

The web is made sufficient to resist all shearing strains, which consideration may determine $t$, although for practical reasons in the

present work the webs were made much heavier than this requirement would demand.

For any particular case $a$, $b$, $d_1$, $d_2$, $T_1$, and $T_2$ are known from the stress diagram. If their values and the maximum allowable intensity of compression be substituted for $f_1$ and $f_2$, equations 19 and 20 become quite simple and may readily be solved for $F_1$ and $F_2$.

This method is direct, and it was found to require very much less time than the tentative process.

In many frames of the shape used the lower flange was determined by the minimum allowable section. By substituting $F_2$ in equation 19, $F_1$ may be found at once.

After $F_1$ and $F_2$ are found by equations (19) and (20), they may be readily checked by equations (13) and (14). This was done in all cases.

The lower or downstream flange is relatively light, and consists of two angles reenforced at their ends.

The section required for the upstream flange is in most cases large. It consists of two heavy angles, a certain amount of the sheathing, and a cover plate, which acts also as a splice plate for the sheathing.

What part the sheathing plates play in resisting flange strain is in doubt. Some designers neglect its action on account of the doubt and others would consider the entire sheathing as part of the flanges. That part of the sheathing plate which is connected to the flange angles must certainly act with the rest of the flange in resisting strain, since any change of length of the angles must cause a like change in that part of the plate which is attached to the angles.

The uncertainty lies in the inability to determine just how far away from the flange this action extends.

In the present work the flange section has been determined for the low-unit stress of 10,000 pounds per square inch, and when two 6-inch angles are used a strip of sheathing 16 inches wide has been counted as part of the flange section, and when two 4-inch angles are used a strip of sheathing 12 inches wide was counted. The probability is that the sheathing has much greater effect than has been assumed, reducing the maximum stress to, say, seven or eight thousand pounds per square inch. On the other hand, even should the sheathing not act at all the stress in the flanges would not be excessive.

## VERTICAL FRAMING.

The vertical system of framing consists of the quoin and miter posts already described and two systems of vertical frames built in between the horizontals. They are shown in fig. 4, plate 70.

These frames, when combined with heavy vertical plates, which extend from top to bottom on each side of the gate, form girders of considerable strength.

They are not, however, introduced for the purpose of carrying any part of the load, but to stiffen the whole structure.

In the middle of the gates for the 80-foot locks, a system of light frames is introduced to stiffen the flanges and webs of the horizontal frames.

EFFECT OF VERTICAL STIFFNESS.

The ideal condition of distribution of loads among the frames of the gate would be for each horizontal frame to resist the water pressure which falls upon it. This condition can not exist, however, so long as the gate has any vertical stiffness and bears against the sill.

It is impracticable to build a gate with no vertical stiffness, and in fact impossible if curved skin plates are used, for the curved sheathing forms a strong vertical girder especially as it is stiffened very frequently.

This sheathing, when combined with the quoin and miter posts and the other vertical framing necessary, makes the gate a vertical girder, which has the effect of changing the loading of the horizontal frames very decidedly from that due to direct water pressure. This may be seen from the following illustration:

Let fig. 12 be a transverse section of a gate taken at the middle of one leaf, acted upon by a head of water H+D on one side and D on the other. If O be the origin of coordinates, the axis of X being horizontal, the abscissas of the line *abc* will represent the intensities of water pressure at any point on *af*.

If each of the horizontal frames were proportioned to resist with the same stress simply the water pressure that falls upon it, and there were no contact at the sill, then the whole section would deflect to a new position A′O′ parallel to AO. If, however, it is held at the sill and has vertical strength, it will take the position A″O.

The horizontal frames near the bottom of the gate will be relieved of a part of their load, some of which will be carried to the sill and the remainder to the upper horizontal frames, which will now be overloaded. To meet this overloading and also for practical reasons, the horizontal frames in the upper part of the gate must be made stronger than would be required to resist simply the load of water pressure which comes upon them.

To determine the distribution of the loads upon the horizontal frames is important. The problem, however, is somewhat complicated since it involves the elasticity of every part of the gate and is therefore not soluble by the equations of statics, and for the same reason the solution can not precede the design, but must follow and be a check upon it.

The determination of the distribution of the loads among the horizontal frames answers the two questions that are of prime importance in connection with the subject.

First. Are the horizontal frames properly proportioned? (The danger exists that the upper frames will be overloaded when the gate bears against the sill, and that the lower frames will be overloaded if the gate does not touch the sill.)

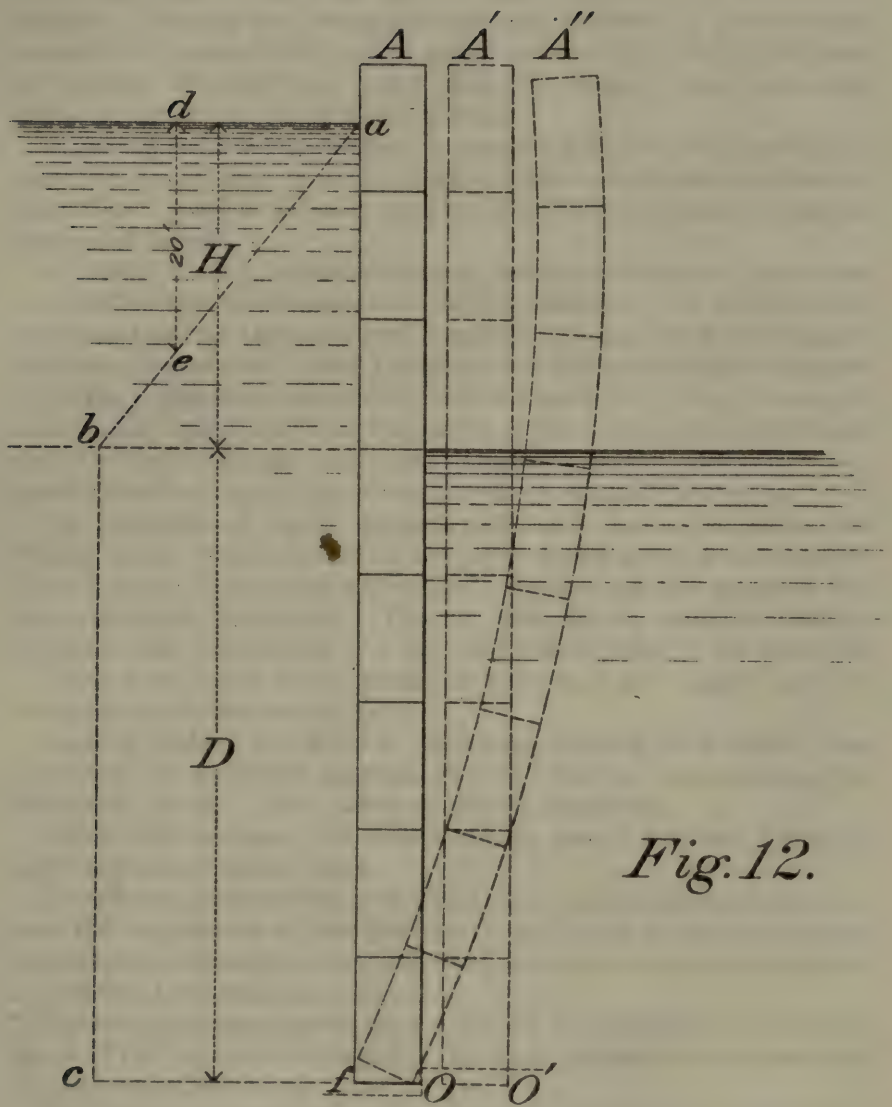


*Fig. 12.*

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Second. Will the deflection of the gate be such as to overstrain the vertical system?

The earliest record that we have of an attempt to solve this problem is the Annales des Ponts et Chaussées for 1850, in which M. Chevalier gives an account of a series of experiments upon wooden models. From the results of these experiments he drew the conclusion that the horizontal frames should be made of equal strength and be equally spaced. This rule has been quite generally followed by French engineers to the present time, and it seems to be a very good one for most of the gates that they have had to deal with, namely, tidal gates, and gates for locks, the lift of which is small.

In 1867 M. Lavoinne published in Annales des Ponts et Chaussées a paper on the subject, in which he gave a very complicated analysis of the effect of vertical stiffness upon the distribution of loads among the horizontal frames.

In 1886 M. Galliot published also in Annales des Ponts et Chaussées the results of his investigations of the same subject. He worked upon the same lines as Lavoinne and obtained formulæ which give practically the same results. Both Lavoinne and Galliot made their analyses upon the supposition that the horizontal frames are of equal strength and equally spaced and that the gate is of the same material throughout. In their analyses they were obliged to make numerous other assumptions and approximations in order to simplify the work.

The condition of equal strength and equal spacing of horizontal frames is far from existing in the gates which have been designed for the locks of the deep waterways. Neither are the gates of the same material throughout. The fact that timber has been used in the quoin and miter posts is a very important factor in the problem.

These facts make the formulæ of Lavoinne and Galliot entirely inapplicable to the case in hand.

Captain Hodges, in his book "Notes on Mitering Lock Gates," has developed an excellent practical rule for use in proportioning the horizontal frames. It is, however, purely empirical.

Other than the cases just mentioned, no record has been found of any solutions of this problem.

As none of the solutions mentioned above are entirely satisfactory, and the importance of the problem is such that it can not well be neglected, considerable attention has been given to the developing of a method of treating the subject.

Numerous measurements were made of the deflection of the steel gates of the Poe lock at Sault Ste. Marie as a check on the results of the theoretical analysis.

The method of treating the problem which has been developed is believed to be theoretically correct, and its results agree very closely with the results of the measurements taken on the Poe locks gates.

The framing of the gate consists of a series of horizontal frames

and practically a single vertical girder covering the entire gate. This vertical girder consists of the quoin and miter posts, two vertical frames, and the curved skin plates. All of these taken together form a girder of considerable stiffness.

This vertical girder may be considered to have a moment of inertia equal to the moment of inertia of all these parts considered as a single piece, so long as no buckling takes place in the skin plates. A certain amount of buckling will no doubt occur, but as the skin plates are stiffened very frequently they will develop a very large percentage of their full strength.

In the following analysis the assumption is made that no bending occurs in the horizontal frames. As a matter of fact, bending will nearly always occur, even when the horizontal frames are circular arches, and it will always occur in the frame shown in the adopted designs. The deflection of the gate due to bending of the horizontal frames is, however, insignificant compared to that caused by shortening of the frames under compression.

As an example, consider the horizontal frame next to the bottom of the upper gate for the lock at Oriskany, N. Y., shown on plate 72.

The deflection of the miter post, due to shortening of the gate, is 1.6 inches, according to equation (21).

The positive bending moment under normal conditions takes place along a length of about 15 feet in the middle of the horizontal frame. Outside this range the line of thrust lies either on or below the center of gravity of the sections. Computing the maximum deflections of this same horizontal frame, caused by bending, we get at the middle only 0.09 inch, which is small in comparison with 1.6 inches, due to shortening of the gate.

The strength of the vertical girder is distributed by the skin plates nearly uniformly over the entire width of the leaf and may be taken quite so. Under the assumption that no bending occurs in the horizontal frame, the deflection of any frame will vary uniformly from 0 at the quoin post to a maximum at the miter post.

The resistance, after deflection of a vertical beam of uniform strength and a width equal to the width of the gate, will also vary in the same way. The center of resistance will therefore be at a point two-thirds of the distance from the quoin post to the miter post.

The magnitude of this resistance will be the force required to deflect the whole beam one-half the deflection at the miter post.

Fig. 13 represents an isometric projection of the frames of a miter-ing gate.

*qq* represents the hollow quoins.

*mm* represents the center line of the meeting faces.

$F_0F_1$, etc., represent the horizontal frames.

*gg* represents the center line of the vertical girder.

The full lines represent the position of the various parts of the gate closed, but with no pressure upon it.

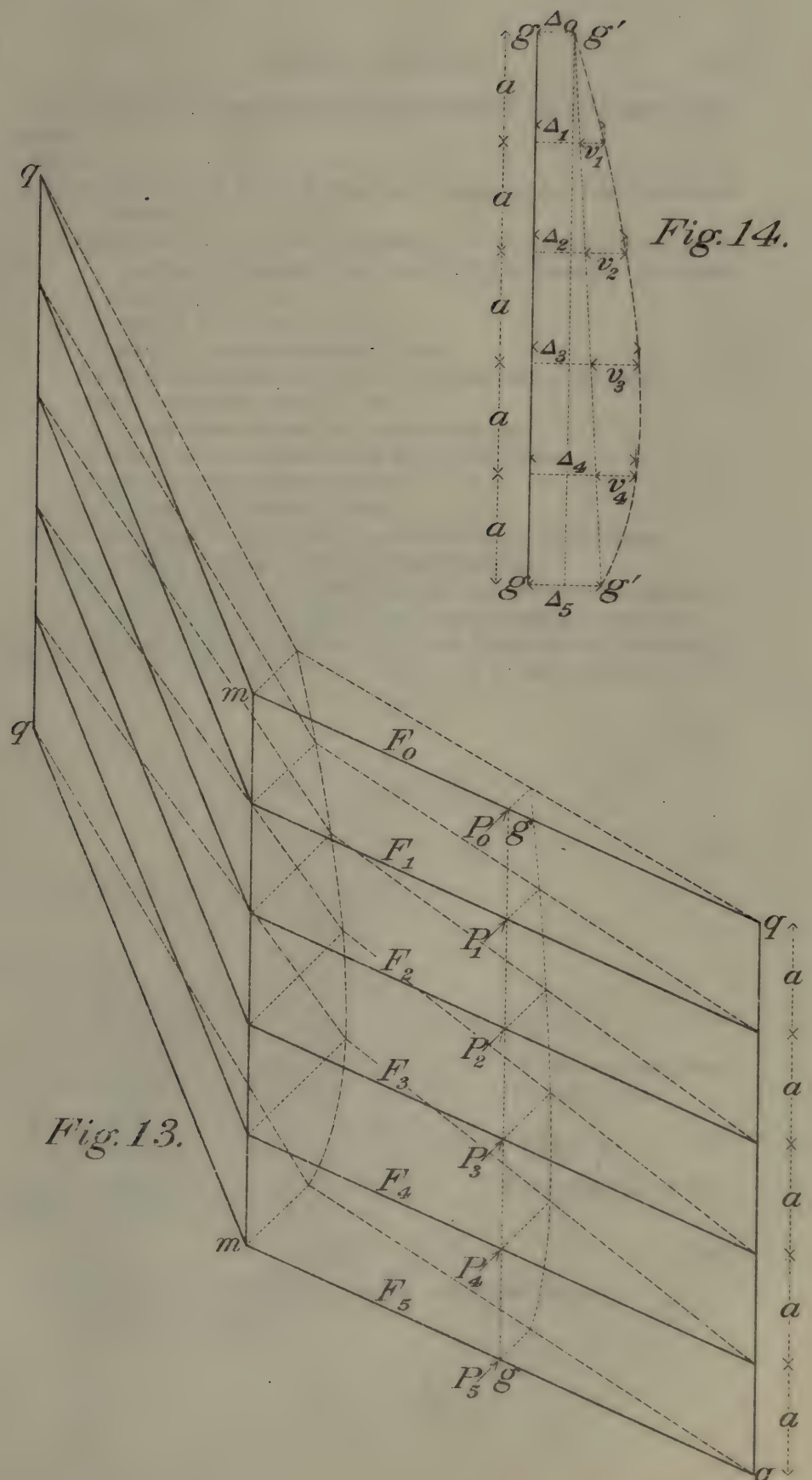

g
Δ0
g′
a
Δ1
v1
a
Δ2
v2
a
Δ3
v3
a
Δ4
v4
a
g
Δ5
g′
q
q
m
m
F0
F1
F2
F3
F4
F5
P0
P1
P2
P3
P4
P5
g
g
q
a
a
a
a
a
a

Fig. 14.

Fig. 13.

The broken lines represent the position which the gate takes under stress.

Let—

$2\triangle$=deflection of miter post at any intersection with a horizontal frame.

T=axial thrust in horizontal frame. This thrust is very nearly constant throughout the length of the frame. (See strain sheet, fig. 8.)

L=length of horizontal frame.

L′=length of steel in horizontal frame.

$t$=combined thickness of timber in quoin and miter post.

$r$=rise of sill=$v\ o_1$, fig. 3.

A′=sectional area of steel in horizontal frame.

A″=area of wood compressed by horizontal frame.

E′=modulus of elasticity of steel.

E″=modulus of elasticity of wood.

$d$ L=the change of length of a horizontal frame under stress.

P=the water pressure on any horizontal frame.

X=the reaction of any horizontal frame against the vertical girder, the direction of water pressure being taken as positive.

Let the horizontal frames be numbered from the top downward, beginning with 0, and let all subscripts refer to this numbering.

$$2\triangle=\frac{\mathrm{L}\,d\,\mathrm{L}}{r}$$

but

$$d\,\mathrm{L}=\mathrm{T}\left(\frac{\mathrm{L}'}{\mathrm{A}'\mathrm{E}'}+\frac{t}{\mathrm{A}''\mathrm{E}''}\right)$$

$$2\triangle=\frac{\mathrm{L}}{r}\,\mathrm{T}\left(\frac{\mathrm{L}'}{\mathrm{A}'\mathrm{E}'}+\frac{t}{\mathrm{A}''\mathrm{E}''}\right) \quad . \quad . \quad . \quad . \quad . \quad (21)$$

and taking moments about the hollow quoin

$$\mathrm{T}=\frac{\mathrm{P}\,\mathrm{L}}{2\,r}-\frac{2\,\mathrm{X}\,\mathrm{L}}{3\,r}$$

substituting:

$$2\triangle=\mathrm{P}\left[\frac{\mathrm{L}^2}{2\,r^2}\left(\frac{\mathrm{L}'}{\mathrm{A}'\mathrm{E}'}+\frac{t}{\mathrm{A}''\mathrm{E}''}\right)\right]-\mathrm{X}\left[\frac{2\,\mathrm{L}^2}{3\,r^2}\left(\frac{\mathrm{L}'}{\mathrm{A}'\mathrm{E}'}+\frac{t}{\mathrm{A}''\mathrm{E}''}\right)\right] \quad . \quad . \quad (22)$$

The deflection of any point in the center line of the vertical girder will be equal to $\triangle$ or one-half the deflection of the miter post:

$$\triangle=\mathrm{P}\left[\frac{\mathrm{L}^2}{4\,r^2}\left(\frac{\mathrm{L}'}{\mathrm{A}'\mathrm{E}'}+\frac{t}{\mathrm{A}''\mathrm{E}''}\right)\right]-\mathrm{X}\left[\frac{\mathrm{L}^2}{3\,r^2}\left(\frac{\mathrm{L}'}{\mathrm{A}'\mathrm{E}'}+\frac{t}{\mathrm{A}''\mathrm{E}''}\right)\right] \quad . \quad . \quad (23)$$

Let the coefficient of P be represented by A. The coefficient of X is $\frac{4}{3}$ times that of P, so we may write:

$$\triangle=\mathrm{A}\,\mathrm{P}-\frac{4}{3}\mathrm{A}\,\mathrm{X} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (24)$$

The value of A is a constant for each horizontal frame.

We have then—

$$\left.\begin{aligned}
\triangle_0 &= A_0 P_0 - \tfrac{4}{3} A_0 X_0 \\
\triangle_1 &= A_1 P_1 - \tfrac{4}{3} A_1 X_1 \\
\triangle_2 &= A_2 P_2 - \tfrac{4}{3} A_2 X_2 \\
\triangle_3 &= A_3 P_3 - \tfrac{4}{3} A_3 X_3 \\
\triangle_4 &= A_4 P_4 - \tfrac{4}{3} A_4 X_4 \\
\triangle_5 &= A_5 P_5 - \tfrac{4}{3} A_5 X_5
\end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (25)$$

or—

$$\triangle_5 = K.$$

The condition of the sill contact determines the value of $\triangle_5$.

If there is no sill contact the first value of $\triangle_5$ is to be used, or—

$$\triangle_5 = A_5 P_5 - \tfrac{4}{3} A_5 X_5.$$

If the gate bears against the sill, then the deflection is no longer a function of the strength of the lower horizontal frame, but is a certain amount (K), which may usually be taken as zero.

When the gate bears against the sill, $X_5$ will be the sill reaction.

We may express $X_0$ and $X_5$ in terms of $X_1$, $X_2$, $X_3$, and $X_4$. By moments about the bottom of the gate,

$$X_0 = -\tfrac{1}{5}(4 X_1 + 3 X_2 + 2 X_3 + X_4) \quad . \quad . \quad . \quad . \quad (26)$$

and about top of gate,

$$X_5 = -\tfrac{1}{5}(X_1 + 2 X_2 + 3 X_3 + 4 X_4) \quad . \quad . \quad . \quad . \quad (27)$$

Equations (25) then become:

$$\left.\begin{aligned}
\triangle_0 &= A_0 P_0 + \tfrac{4}{15} A_0 (4 X_1 + 3 X_2 + 2 X_3 + X_4) \\
\triangle_1 &= A_1 P_1 - \tfrac{4}{3} A_1 X_1 \\
\triangle_2 &= A_2 P_2 - \tfrac{4}{3} A_2 X_2 \\
\triangle_3 &= A_3 P_3 - \tfrac{4}{3} A_3 X_3 \\
\triangle_4 &= A_4 P_4 - \tfrac{4}{3} A_4 X_4 \\
\triangle_5 &= A_5 P_5 + \tfrac{4}{15} A_5 (X_1 + 2 X_2 + 3 X_3 + 4 X_4)
\end{aligned}\right\} \quad . \quad . \quad (28)$$

or—

$$\triangle_5 = K.$$

Let fig. 14 represent a transverse section of the gate taken on the center line of the vertical girder, in which $g\ g$ represents the center line of the vertical girder before deflection and the curved line $g'\ g'$ represents the same line after deflection takes place.

Let $\triangle_0\ \triangle_1$, etc., $r_1\ r_2$, etc., be as indicated in the figure. Then

$$r_1 = \triangle_1 - \frac{4}{5}\triangle_0 - \frac{1}{5}\triangle_5$$
$$r_2 = \triangle_2 - \frac{3}{5}\triangle_0 - \frac{2}{5}\triangle_5$$
$$r_3 = \triangle_3 - \frac{2}{5}\triangle_0 - \frac{3}{5}\triangle_5$$
$$r_4 = \triangle_4 - \frac{1}{5}\triangle_0 - \frac{4}{5}\triangle_5$$

Substituting the values of $\triangle$ given by equations (28) into the above equations, we have for gate without contact at sill:

$$\left.\begin{aligned}
-r_1 &= \left(\frac{4}{3}A_1 + \frac{64}{75}A_0 + \frac{4}{75}A_5\right)X_1 + \left(\frac{48}{75}A_0 + \frac{8}{75}A_5\right)X_2 + \left(\frac{32}{75}A_0 + \frac{12}{75}A_5\right)X_3 + \left(\frac{16}{75}A_0 + \frac{16}{75}A_5\right)X_4 - A_1P_1 + \frac{4}{5}A_0P_0 + \frac{1}{5}A_5P_5 \\
-r_2 &= \left(\frac{48}{75}A_0 + \frac{8}{75}A_5\right)X_1 + \left(\frac{4}{3}A_2 + \frac{36}{75}A_0 + \frac{16}{75}A_5\right)X_2 + \left(\frac{24}{75}A_0 + \frac{24}{75}A_5\right)X_3 + \left(\frac{12}{75}A_0 + \frac{32}{75}A_5\right)X_4 - A_2P_2 + \frac{3}{5}A_0P_0 + \frac{2}{5}A_5P_5 \\
-r_3 &= \left(\frac{32}{75}A_0 + \frac{12}{75}A_5\right)X_1 + \left(\frac{24}{75}A_0 + \frac{24}{75}A_5\right)X_2 + \left(\frac{4}{3}A_3 + \frac{16}{75}A_0 + \frac{36}{75}A_5\right)X_3 + \left(\frac{8}{75}A_0 + \frac{48}{75}A_5\right)X_4 - A_3P_3 + \frac{2}{5}A_0P_0 + \frac{3}{5}A_5P_5 \\
-r_4 &= \left(\frac{16}{75}A_0 + \frac{16}{75}A_5\right)X_1 + \left(\frac{12}{75}A_0 + \frac{32}{75}A_5\right)X_2 + \left(\frac{8}{75}A_0 + \frac{48}{75}A_5\right)X_3 + \left(\frac{4}{3}A_4 + \frac{4}{75}A_0 + \frac{64}{75}A_5\right)X_4 - A_4P_4 + \frac{1}{5}A_0P_0 + \frac{4}{5}A_5P_5
\end{aligned}\right\} (29)$$

And for contact at sill:

$$\left.\begin{aligned}
-r_1 &= \left(\frac{4}{3}A_1 + \frac{64}{75}A_0\right)X_1 + \frac{48}{75}A_0X_2 + \frac{32}{75}A_0X_3 + \frac{16}{75}A_0X_4 - A_1P_1 + \frac{4}{5}A_0P_0 + \frac{1}{5}K \\
-r_2 &= \frac{48}{75}A_0X_1 + \left(\frac{4}{3}A_2 + \frac{36}{75}A_0\right)X_2 + \frac{24}{75}A_0X_3 + \frac{12}{75}A_0X_4 - A_2P_2 + \frac{3}{5}A_0P_0 + \frac{2}{5}K \\
-r_3 &= \frac{32}{75}A_0X_1 + \frac{24}{75}A_0X_2 + \left(\frac{4}{3}A_3 + \frac{16}{75}A_0\right)X_3 + \frac{8}{75}A_0X_4 - A_3P_3 + \frac{2}{5}A_0P_0 + \frac{3}{5}K \\
-r_4 &= \frac{16}{75}A_0X_1 + \frac{12}{75}A_0X_2 + \frac{8}{75}A_0X_3 + \left(\frac{4}{3}A_4 + \frac{4}{75}A_0\right)X_4 - A_4P_4 + \frac{1}{5}A_0P_0 + \frac{4}{5}K
\end{aligned}\right\} (30)$$

The equations given above express the deflections $r_1$ $r_2$, etc., in terms of the loads and the properties of the horizontal frames.

We will now derive independently the value of the same deflections expressed in terms of the loads and the properties of the vertical girder.

We will first demonstrate the following proposition:

If a simple beam be acted upon by a series of transverse forces $P_1$ $P_2$, etc., then

$$r_n = \int_0^L \frac{M \, d \, M}{E \, I \, d \, P_n} d \, L$$

in which

M = the bending moment at any point.

E = the modulus of elasticity of the material.

I = the moment of inertia of the beam.

$P_n$ = any transverse force.

$v_n$ = the movement of the point of application of the force $P_n$ with respect to a straight line joining any two points of the beam (usually points of support). $v_n$ must be measured in the direction of the force $P_n$.

L = the length of the beam.

In fig. 15:

Let $p_1$ $p_2$ $p_3$ $p_4$ $p_5$ $p_6$ represent the center line of a straight beam under the action of the forces $P_1$ $P_2$ . . . $P_6$.

Let $p_1$ $p_4$ be considered fixed points.

The position of the center line of the beam without load is a straight line drawn through $p_1$ $p_4$.

Let the movement of the points $p_1$ $p_2$, etc., under the action of the forces $P_1$ $P_2$, etc., be $v_1$ $v_2$, etc.

In passing from one condition of loading to another work is done.

The total work of all the external forces acting upon the beam is—

$$W = \sum \frac{P r}{2}.$$

By the doctrine of the conservation of energy, this must be equaled by the internal work done in distorting the beam. This internal work is done in lengthening and compressing the material, and stored as potential energy in the material to be given back if the forces are removed and the beam springs back to its initial position.

In fig. 16:

Let $c$ $c$ be an infinitesimal portion of length $d$ L of the neutral axis of the beam under stress.

Let $n$ $n'$ and $m$ $m'$ be normal sections.

Let $i$ be the angle $n'$ $c$ $r'$.

Let $y$ be the distance from the neutral axis to any point $q$ on the section $n$ $n'$.

*Fig. 15.*

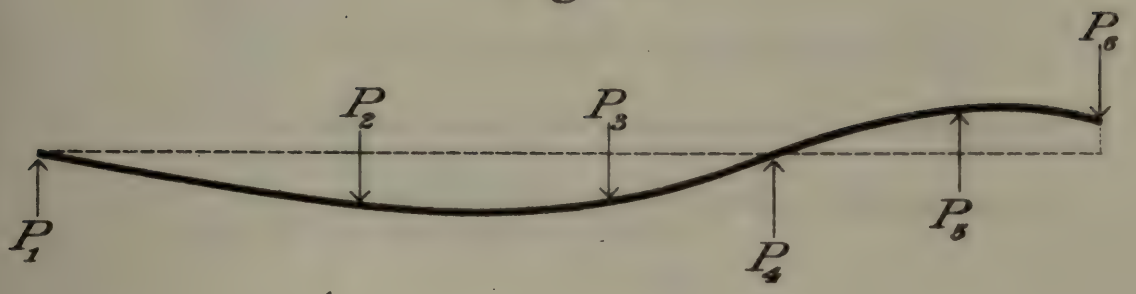
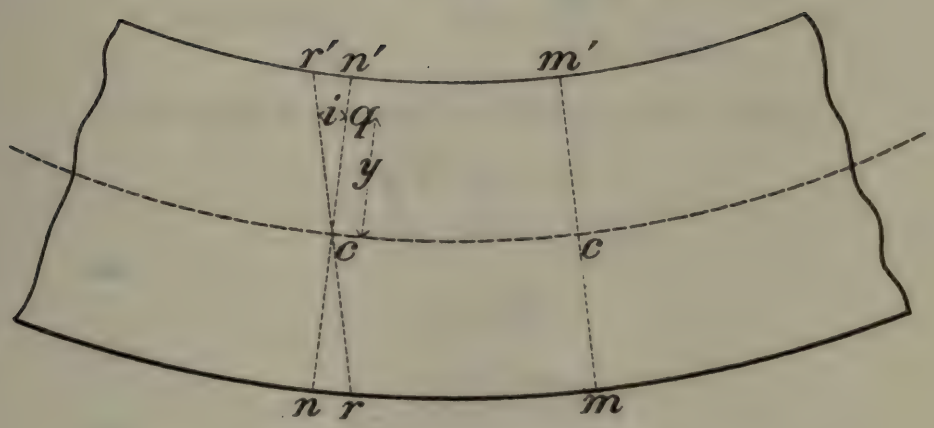
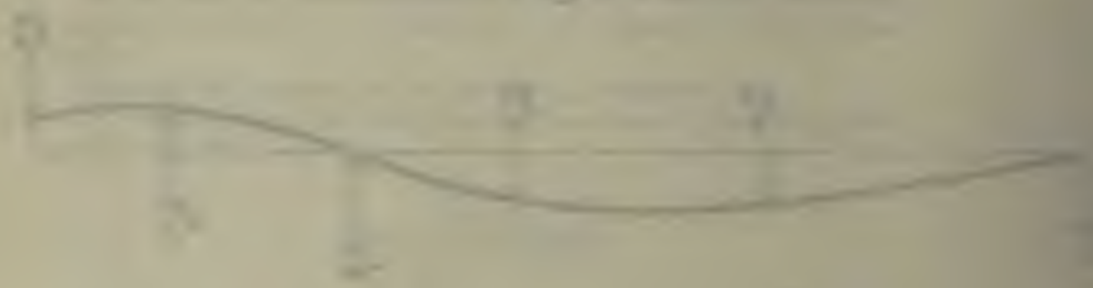



*Fig. 16.*





Let $f$ be the stress at point $q$.
Let $y_1 = c\ n$.
Let $y_2 = c\ n'$.

Before the beam was stressed $n\ n'$ was parallel to $m\ m'$, or in a position $r\ r'$.

The average force acting upon unit area at $q$ is $\frac{i}{2} f$, and the distance through which it acts is $y\ i$.

Then neglecting the distortion caused by shear, which is practically zero, the work done on an area $a$ at $q$ is:

$$d\ w = \frac{f\ a\ y\ i}{2}.$$

The work upon the whole prism $n\ n'\ m'\ m$ is:

$$W = \sum_{-y_1}^{y_2} \frac{f\ a\ y\ i}{2}.$$

The total internal work in the whole beam is:

$$W = \sum_{0}^{L} \sum_{-y_1}^{y_2} \frac{f\ a\ y\ i}{2}.$$

The total external work done upon the beam is:

$$W = \frac{P_1\ v_1 + P_2\ v_2 \quad . \quad . \quad . \quad P_n\ v_n}{2}.$$

Equating external with internal work and clearing of fractions, we have:

$$P_1\ v_1 + P_2\ v_2 \quad . \quad . \quad . \quad P_n\ v_n = \sum_{0}^{L} \sum_{-y_1}^{y_2} f\ a\ y\ i.$$

Differentiating this equation with respect to $P_n$, we have:

$$v_n = \sum_{0}^{L} \sum_{-y_1}^{y_2} \frac{d\ f}{d\ P_n}\ a\ y\ i.$$

But,

$$f = \frac{M\ y}{I}$$

Then,

$$\frac{d\ f}{d\ P_n} = \frac{d\ M\ y}{d\ P_n\ I}$$

and

$$y\ i = \frac{f\ d\ L}{E} = \frac{M\ y\ d\ L}{E\ I}$$

Substituting the values of $\frac{df}{dP_n}$ and $y\,i$ we have:

$$v_n = \int_0^L \sum_{-y_1}^{y_2} \frac{dM}{dP_n} \frac{y}{I} \frac{a\,M\,y\,dL}{E\,I} = \int_0^L \frac{dM}{dP_n} \frac{M}{E\,I^2} \sum_{-y_1}^{y_2} a\,y^2\,dL$$

but $$\sum_{-y_1}^{y_2} a\,y^2 = I$$

We therefore have:

$$v_n = \int_0^L \frac{dM}{dP_n} \frac{M}{E\,I}\,dL \qquad \text{Q. E. D.}$$

Turning now to the vertical girder of the gate, the forces acting on it are $X_0\ X_1\ X_2$, etc.

Let $M_1$ be the bending moment at any point in the top panel of the vertical girder.

Let $M_2\ M_3$, etc., be the moments in the second and third panels etc.,

Let $y$ be the distance of any point in any panel from the horizontal frame next below it.

$$M_5 = y\,X_5 = -\,y\,(\frac{X_1}{5} + \frac{2}{5}\,X_2 + \frac{3}{5}\,X_3 + \frac{4}{5}\,X_4)$$

$$\frac{dM_5}{dX_1} = -\frac{y}{5}$$

$$\frac{dM_5}{dX_2} = -\frac{2}{5}\,y$$

$$\frac{dM_5}{dX_3} = -\frac{3}{5}\,y$$

$$\frac{dM_5}{dX_4} = -\frac{4}{5}\,y$$

$$\frac{dM_5}{dX_1}\frac{M_5}{EI} = \frac{y^2}{25\,EI}(X_1 + 2\,X_2 + 3\,X_3 + 4\,X_4)$$

$$\int_0^a \frac{dM_5}{dX_1}\frac{M_5}{EI}dy = \frac{a^3}{150\,EI}(2\,X_1 + 4\,X_2 + 6\,X_3 + 8\,X_4)$$

$$\frac{dM_5}{dX_2}\frac{M_5}{EI} = \frac{y^2}{25\,EI}(2\,X_1 + 4\,X_2 + 6\,X_3 + 8\,X_4)$$

$$\int_0^a \frac{dM_5}{dX_2}\frac{M_5}{EI}dy = \frac{a^3}{150\,EI}(4\,X_1 + 8\,X_2 + 12\,X_3 + 16\,X_4)$$

In the same way,

$$\int_{\circ}^{a} \frac{d\,M_5}{d\,X_3}\frac{M_5}{EI}dy=\frac{a^3}{150\,EI}(6\,X_1+12\,X_2+18\,X_3+24\,X_4)$$

$$\int_{\circ}^{a} \frac{d\,M_5}{d\,X_4}\frac{M_5}{EI}dy=\frac{a^3}{150\,EI}(8\,X_1+16\,X_2+24\,X_3+32\,X_4)$$

$$M_4=-\frac{1}{5}(a+y)\,X_1-\frac{2}{5}(a+y)X_2-\frac{3}{5}(a+y)X_3-\frac{1}{5}(4a-y)\,X_4$$

$$\frac{d\,M_4}{d\,X_1}=-\frac{1}{5}(a+y)$$

$$\frac{d\,M_4}{d\,X_2}=-\frac{2}{5}(a+y)$$

$$\frac{d\,M_4}{d\,X_3}=-\frac{3}{5}(a+y)$$

$$\frac{d\,M_4}{d\,X_4}=-\frac{1}{5}(4a-y)$$

$$\frac{d\,M_4}{d\,X_1}\frac{M_4}{E\,I}=\frac{(a+y^2)}{25\,E\,I}(X_1+2\,X_2+3\,X_3)+\frac{4\,a^2+3\,ay-y^2}{25\,E\,I}\,X_4$$

$$\int_{\circ}^{a} \frac{d\,M_4}{d\,X_1}\frac{M_4}{E\,I}\,d\,y=\frac{a^3}{150\,E\,I}(14\,X_1+28\,X_2+42\,X_3+31\,X_4)$$

In like manner,

$$\int_{\circ}^{a} \frac{d\,M_4}{d\,X_2}\frac{M_4}{E\,I}\,d\,y=\frac{a^3}{150\,E\,I}(28\,X_1+56\,X_2+84\,X_3+62\,X_4)$$

$$\int_{\circ}^{a} \frac{d\,M_4}{d\,X_3}\frac{M_4}{E\,I}\,d\,y=\frac{a^3}{150\,E\,I}(42\,X_1+84\,X_2+126\,X_3+93\,X_4)$$

$$\int_{\circ}^{a} \frac{d\,M_4}{d\,X_4}\frac{M_4}{E\,I}\,d\,y=\frac{a^3}{150\,E\,I}(31\,X_1+62\,X_2+93\,X_3+74\,X_4)$$

For the third panel,

$$M_3=\frac{2\,a+y}{5}(X_1+2\,X_2)-\frac{2}{5}(3\,a-y)\,X_3-\frac{1}{5}(3\,a-y)\,X_4$$

$$\int_{\circ}^{a} \frac{d\,M_3}{d\,X_1}\frac{M_3}{E\,I}\,d\,y=\frac{a^3}{150\,E\,I}(38\,X_1+76\,X_2+74\,X_3+37\,X_4)$$

$$\int_{\circ}^{a} \frac{d\,M_3}{d\,X_2}\frac{M_3}{E\,I}\,d\,y=\frac{a^3}{150\,E\,I}(76\,X_1+152\,X_2+148\,X_3+74X_4)$$

$$\int_0^a \frac{d\,M_3}{d\,X_3}\frac{M_3}{E\,I}\,d\,y = \frac{a^3}{150\,E\,I}(74\,X_1+148\,X_2+152\,X_3+76\,X_4)$$

$$\int_0^a \frac{d\,M_3}{d\,X_4}\frac{M_3}{E\,I}\,d\,y = \frac{a^3}{150\,E\,I}(37\,X_1+74\,X_2+76\,X_3+38\,X_4)$$

For the second panel,

$$M_2 = -\frac{1}{5}(3\,a-y)\,X_1 - \frac{3}{5}(2\,a-y)\,X_2 - \frac{2}{5}(2\,a-y)\,X_3 - \frac{1}{5}(2\,a-y)\,X_4$$

$$\int_0^a \frac{d\,M_2}{d\,X_1}\frac{M_2}{E\,I}\,d\,y = \frac{a^3}{150\,E\,I}(74\,X_1+93\,X_2+62\,X_3+31\,X_4)$$

$$\int_0^a \frac{d\,M_2}{d\,X_2}\frac{M_2}{E\,I}\,d\,y = \frac{a^3}{150\,E\,I}(93\,X_1+126\,X_2+84\,X_3+42\,X_4)$$

$$\int_0^a \frac{d\,M_2}{d\,X_3}\frac{M_2}{E\,I}\,d\,y = \frac{a^3}{150\,E\,I}(62\,X_1+84\,X_2+56\,X_3+28\,X_4)$$

$$\int_0^a \frac{d\,M_2}{d\,X_4}\frac{M_2}{E\,I}\,d\,y = \frac{a^3}{150\,E\,I}(31\,X_1+42\,X_2+28\,X_3+14\,X_4)$$

For the first panel,

$$M_1 = -\frac{4}{5}(a-y)\,X_1 - \frac{3}{5}(a-y)\,X_2 - \frac{2}{5}(a-y)\,X_3 - \frac{1}{5}(a-y)\,X_4$$

$$\int_0^a \frac{d\,M_1}{d\,X_1}\frac{M_1}{E\,I}\,d\,y = \frac{a^3}{150\,E\,I}(32\,X_1+24\,X_2+16\,X_3+8\,X_4)$$

$$\int_0^a \frac{d\,M_1}{d\,X_2}\frac{M_1}{E\,I}\,d\,y = \frac{a^3}{150\,E\,I}(24\,X_1+18\,X_2+12\,X_3+6\,X_4)$$

$$\int_0^a \frac{d\,M_1}{d\,X_3}\frac{M_1}{E\,I}\,d\,y = \frac{a^3}{150\,E\,I}(16\,X_1+12\,X_3+8\,X_3+4\,X_4)$$

$$\int_0^a \frac{d\,M_1}{d\,X_4}\frac{M_1}{E\,I}\,d\,y = \frac{a^3}{150\,E\,I}(8\,X_1+6\,X_2+4\,X_3+2\,X_4)$$

$$v_1=\int_0^{5a}\frac{d\,\mathrm{M}\,\mathrm{M}}{d\,\mathrm{X}_1\,\mathrm{E}\,\mathrm{I}}\,d\,\mathrm{L}=\int_0^{a}\frac{d\,\mathrm{M}_1\,\mathrm{M}_1}{d\,\mathrm{X}_1\,\mathrm{E}\,\mathrm{I}}\,d\,y+\int_0^{a}\frac{d\,\mathrm{M}_2\,\mathrm{M}_2}{d\,\mathrm{X}_1\,\mathrm{E}\,\mathrm{I}}\,d\,y+\int_0^{a}\frac{d\,\mathrm{M}_3\,\mathrm{M}_3}{d\,\mathrm{X}_1\,\mathrm{E}\,\mathrm{I}}\,dy$$

$$+\int_0^{a}\frac{d\,\mathrm{M}_4\,\mathrm{M}_4}{d\,\mathrm{X}_1\,\mathrm{E}\,\mathrm{I}}\,d\,y+\int_0^{a}\frac{d\,\mathrm{M}_5\,\mathrm{M}_5}{d\,\mathrm{X}_1\,\mathrm{E}\,\mathrm{I}}\,d\,y=\frac{a^3}{150\,\mathrm{E}\,\mathrm{I}}\,(160\,\mathrm{X}_1+225\,\mathrm{X}_2+200\,\mathrm{X}_3$$

$+115\,\mathrm{X}_4)$

In the same way

$$v_2=\frac{a^3}{150\,\mathrm{E}\,\mathrm{I}}\,(225\,\mathrm{X}_1+360\,\mathrm{X}_2+340\,\mathrm{X}_3+200\,\mathrm{X}_4)$$

$$v_3=\frac{a^3}{150\,\mathrm{E}\,\mathrm{I}}\,(200\,\mathrm{X}_1+340\,\mathrm{X}_2+360\,\mathrm{X}_3+225\,\mathrm{X}_4)$$

$$v_4=\frac{a^3}{150\,\mathrm{E}\,\mathrm{I}}\,(115\,\mathrm{X}_1+200\,\mathrm{X}_2+225\,\mathrm{X}_3+160\,\mathrm{X}_4)$$

Equating these values of $v_1$ $v_2$, etc., with those in group of equations (29) and (30), we have, after clearing of fractions, for no contact at sill:

$$(200\,\mathrm{A}_1+128\,\mathrm{A}_0+8\,\mathrm{A}_5+\frac{160\,a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_1+(96\,\mathrm{A}_0+16\,\mathrm{A}_5+\frac{225\,a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_2+(64\,\mathrm{A}_0$$

$$+24\mathrm{A}_5+\frac{200\,a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_3+(32\,\mathrm{A}_0+32\,\mathrm{A}_5+\frac{115\,a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_4-150\,\mathrm{A}_1\,\mathrm{P}_1+120\,\mathrm{A}_0\,\mathrm{P}_0$$

$$+30\,\mathrm{A}_5\,\mathrm{P}_5=0$$

$$\left.\begin{aligned}&(96\,\mathrm{A}_0+16\,\mathrm{A}_5+\frac{225a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_1+(200\,\mathrm{A}_2+72\,\mathrm{A}_0+32\,\mathrm{A}_5+\frac{360a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_2\\&+(48\,\mathrm{A}_0+48\,\mathrm{A}_5+\frac{340a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_3+(24\,\mathrm{A}_0+64\,\mathrm{A}_5+\frac{200a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_4-150\\&\mathrm{A}_2\,\mathrm{P}_2+90\,\mathrm{A}_0\,\mathrm{P}_0+60\,\mathrm{A}_5\,\mathrm{P}_5=0.\\&(64\,\mathrm{A}_0+24\,\mathrm{A}_5+\frac{200a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_1+(48\,\mathrm{A}_0+48\,\mathrm{A}_5+\frac{340a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_2+(200\,\mathrm{A}_3+\\&32\,\mathrm{A}_0+72\,\mathrm{A}_5+\frac{360a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_3+(16\,\mathrm{A}_0+96\,\mathrm{A}_5+\frac{225a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_4-150\,\mathrm{A}_3\,\mathrm{P}_3\\&+60\,\mathrm{A}_0\,\mathrm{P}_0+90\,\mathrm{A}_5\,\mathrm{P}_5=0.\\&(32\,\mathrm{A}_0+32\,\mathrm{A}_5+\frac{115a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_1+(24\,\mathrm{A}_0+64\,\mathrm{A}_5+\frac{200a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_2+(16\,\mathrm{A}_0+\\&96\,\mathrm{A}_5+\frac{225a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_3+(200\,\mathrm{A}_4+8\,\mathrm{A}_0+128\,\mathrm{A}_5+\frac{160a^3}{\mathrm{E}\,\mathrm{I}})\,\mathrm{X}_4-150\,\mathrm{A}_4\mathrm{P}_4\\&+30\,\mathrm{A}_0\,\mathrm{P}_0+120\,\mathrm{A}_5\,\mathrm{P}_5=0.\end{aligned}\right\}(31)$$

For contact at sill—

$$\left.\begin{aligned}
&\left(200\,A_1+128\,A_0+\frac{160a^3}{E\,I}\right)X_1+\left(96\,A_0+\frac{225a^3}{E\,I}\right)X_2+\left(64\,A_0+\frac{200a^3}{E\,I}\right)\\
&\qquad X_3+\left(32\,A_0+\frac{115a^3}{E\,I}\right)X_4-150\,A_1\,P_1+120\,A_0\,P_0+30\,K=0.\\
&\left(96\,A_0+\frac{225a^3}{E\,I}\right)X_1+\left(200\,A_2+72\,A_0+\frac{360a^3}{E\,I}\right)X_2+\left(48\,A_0+\frac{340a^3}{E\,I}\right)\\
&\qquad X_3\left(24\,A_0+\frac{200a^3}{E\,I}\right)X_4-150\,A_2\,P_2+90\,A_0\,P_0+60\,K=0.\\
&\left(64\,A_0+\frac{200a^3}{E\,I}\right)X_1+\left(48\,A_0+\frac{340a^3}{E\,I}\right)X_2+\left(200\,A_3+32\,A_0+\frac{360a^3}{E\,I}\right)\\
&\qquad X_3+\left(16\,A_0+\frac{225a^3}{E\,I}\right)X_4-150\,A_3\,P_3+60\,A_0\,P_0+90\,K=0.\\
&\left(32\,A_0+\frac{115a^3}{E\,I}\right)X_1+\left(24\,A_0+\frac{200a^3}{E\,I}\right)X_2+\left(16\,A_0+\frac{225a^3}{E\,I}\right)X_3+\left(200\right.\\
&\qquad \left.A_4+8\,A_0+\frac{160a^3}{E\,I}\right)X_4-150\,A_4\,P_4+30\,A_0\,P_0+120\,K=0.
\end{aligned}\right\}\quad(32)$$

The only unknown quantities in these equations are $X_1\ X_2\ X_3\ X_4$.

The numerical values of $A_0\ A_1\ A_2\ .\ .\ .\ A_5$ may be substituted and the simultaneous equations solved for $X_1\ X_2$, etc.

These equations apply to a gate with six horizontal frames.

A set of equations may be derived in a similar manner for a gate with any number of horizontal frames. There will always be two fewer equations than there are horizontal frames.

In some of the higher gates there will be as many as 30 horizontal frames. It would be impracticable to attempt the solution of 28 simultaneous equations, and, in fact, it is not necessary to do so. The horizontal frames may be grouped into a few groups, each of which may be then considered a horizontal frame.

It is evident that the error in so doing is due to considering the center line of the vertical girder to be straight between the half panel points. As the curve of the vertical girder is extremely flat, the error in such an assumption must be very slight. We may then group the horizontal frames into six parts equally spaced, and determine the constants, which may then be substituted into equations (31) or (32), as the case may be, and from them the desired loading found.

To make this clearer, let us make the application to one of the gates designed. Fig. 17 represents the section of the lower gate for the 80-foot lock No. 7 of the Tonawanda-Olcott route.

The first diagram shows the arrangement and sectional area of the horizontal frames; the second shows the arrangement and sectional area of the frames after they are grouped.

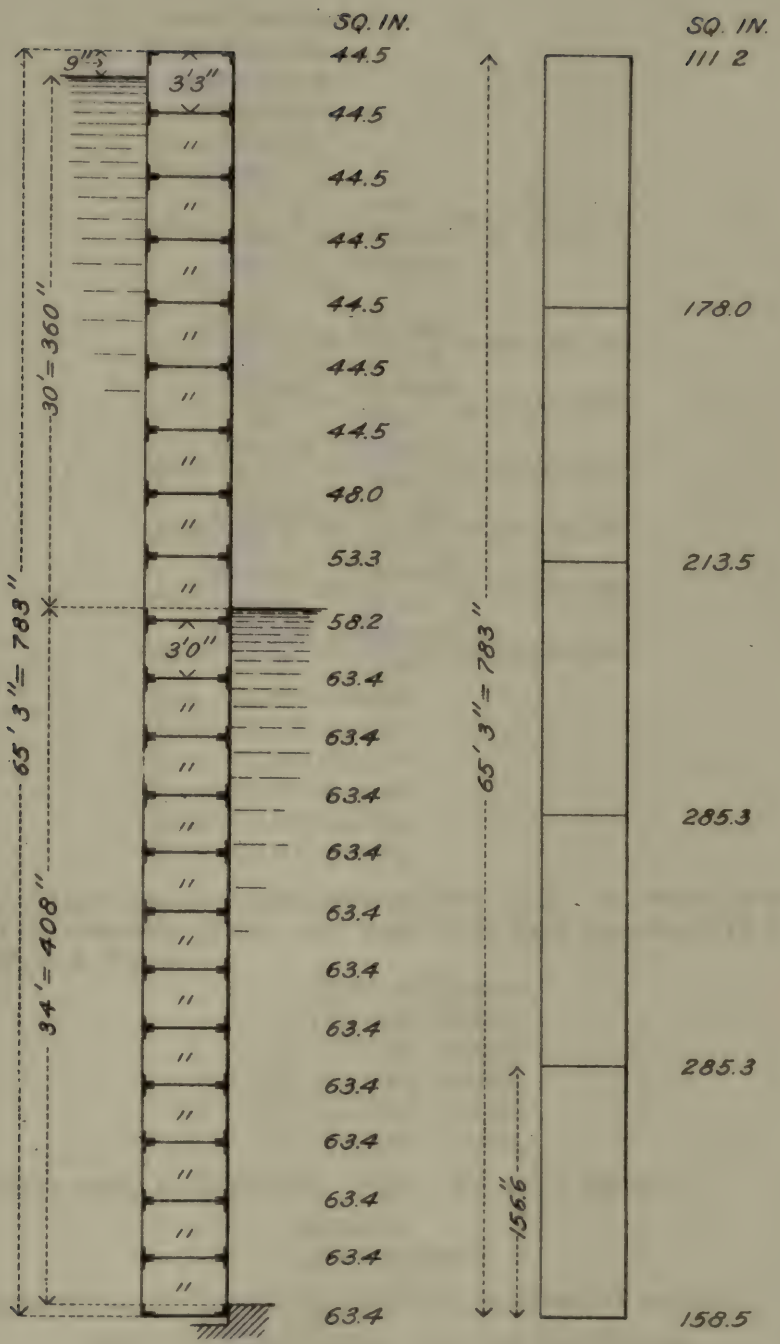

SQ. IN.
SQ. IN.
9"
3'3"
3'0"
65' 3" = 783"
30' = 360"
34' = 408"
44.5
44.5
44.5
44.5
44.5
44.5
44.5
48.0
53.3
58.2
63.4
63.4
63.4
63.4
63.4
63.4
63.4
63.4
63.4
63.4
63.4
63.4
63.4
111 2
178.0
213.5
285.3
285.3
158.5
65' 3" = 783"
156.6"

*Fig. 17.*

$L=552$ see plate 73.
$L'=528$ inches.
$r=200$ inches.
$t=22$ inches.
$E'=29000000$.
$E''=20000$.

$$A=\frac{552^2}{4\times 200^2}\left(\frac{528}{A'\ 29000000}+\frac{22}{A''\ 22,000}\right)$$

$$=\frac{.00003467}{A'}+\frac{.00209484}{A''}$$

$$A_0=\frac{.00003467}{111.25}+\frac{.00209484}{1722.6}=.000,001,525$$

$$A_1=\frac{.00003467}{178}+\frac{.00209484}{3445.2}=.000,000,802$$

$$A_2=\frac{.00003467}{213.5}+\frac{.00209484}{3445.2}=.000,000,770$$

$$A_3=\frac{.00003467}{285.3}+\frac{.00209484}{3445.2}=.000,000,729$$

$$A_4=\frac{.00003467}{285.3}+\frac{.00209484}{3445.2}=.000,000,729$$

$$A_5=\frac{.00003467}{158.5}+\frac{.00209484}{1722.6}=.000,001,433$$

$P_0=$ 47,000 pounds.
$P_1=$ 452,000 pounds.
$P_2=$ 926,000 pounds.
$P_3=$1,100,000 pounds.
$P_4=$1,100,000 pounds.
$P_5=$ 550,000 pounds.

If the gate had no vertical stiffness then $X_0$ $X_1$, etc., would be zero and the deflection of the miter post would, from equation (24), be 2 $A_0$ $P_0$, 2 $A_1$ $P_1$, etc.

2 $A_0$ $P_0$= .1432 inches.
2 $A_1$ $P_1$= .726 inches.
2 $A_2$ $P_2$=1.426 inches.
2 $A_3$ $A_3$=1.604 inches.
2 $A_4$ $P_4$=1.604 inches.
2 $A_5$ $P_5$=1.590 inches.

These values are plotted in the line *a b c*, fig. 1, plate 80.

$I=190000$.
$a=156.6$ inches.

Substituting the known quantities in equations (31) we have:

$$.4784\ X_1+.3272\ X_2+.2714\ X_3+.1743\ X_4-22070=0$$
$$.3272\ X_1+.5803\ X_2+.3790\ X_3+.2676\ X_4-52870=0$$
$$.2714\ X_1+.3790\ X_2+.5484\ X_3+.3198\ X_4-44110=0$$
$$.1748\ X_1+.2676\ X_2+.3198\ X_3+.4531\ X_4-22450=0$$

From which,

$X_1 = -34{,}200$ pounds.
$X_2 = +89{,}100$ pounds.
$X_3 = +50{,}750$ pounds.
$X_4 = -25{,}690$ pounds.

From equations (26) and (27)

$X_0 = -41270$ pounds.
$X_5 = -38730$ pounds.

Substituting now in equations (25):

$\triangle_0 = .156$ inches.
$\triangle_1 = .399$ inches.
$\triangle_2 = .622$ inches.
$\triangle_3 = .754$ inches.
$\triangle_4 = .826$ inches.
$\triangle_5 = .862$ inches.

The deflection of the mitre post will be:

$2\triangle_0 = .312$ inches.
$2\triangle_1 = .798$ inches.
$2\triangle_2 = 1.244$ inches.
$2\triangle_3 = 1.508$ inches.
$2\triangle_4 = 1.652$ inches.
$2\triangle_5 = 1.724$ inches.

These deflections are plotted in fig. 1, plate 80, and the curve of the miter post *gh* is drawn.

Substituting the known quantities in equation (32) and making K=0, we have:

$$.4670\ X_1 + .3043\ X_2 + .2370\ X_3 + .1290 - 45920 = 0$$
$$.3043\ X_1 + .5145\ X_2 + .3102\ X_3 + .1760 - 100570 = 0$$
$$.2370\ X_1 + .3102\ X_2 + .4454\ X_3 + .1824 - 115710 = 0$$
$$.1290\ X_1 + .1760\ X_2 + .1824\ X_3 + .2696 - 117850 = 0$$

Solving,

$X_1 = -112{,}700$ pounds.
$X_2 = 56{,}700$ pounds.
$X_3 = 134{,}700$ pounds.
$X_4 = 363{,}000$ pounds.

And from equations (26) and (27)

$X_0 = -70{,}300$ pounds.
$X_5 = -371{,}400$ pounds.

Substituting these quantities in equation (25) and doubling the value of $\triangle$ we have as the deflection at the miter.

$2\triangle_0 = .429$ inches.
$2\triangle_1 = .964$ inches.
$2\triangle_2 = 1.312$ inches.
$2\triangle_3 = 1.340$ inches.
$2\triangle_4 = .898$ inches.
$2\triangle_5 = 2\ K = 0.$

These values are plotted in fig. 1, plate 80, and the curve of the miter post *f o* drawn.

We are now able to determine the loading on any horizontal frame.

Let the loading on a frame after deflection be equivalent to a certain water pressure P′.

Then

$$P' = P_n - \frac{4}{3} X_n \quad . \quad . \quad . \quad . \quad (33)$$

In which $P_n$ is the water pressure upon the horizontal frame, and $X_n$ is the reaction of the horizontal frame upon the vertical girder.

The deflection of the miter post at any horizontal frame may be found from the curves fig. 1, plate 80.

By substituting this deflection and the proper constants in equation (23) the value of $X_n$ may be found. This substituted in equation (33) gives P′ the load upon the frame.

Using this new loading, the stresses in the frame may be computed as in the beginning.

If, as usually will be the case, the stress of the horizontal frame rather than their loading is desired, they may be arrived at by a much shorter process.

The line *a b c*, fig. 1, plate 80, represents the deflection which the miter post would have if there were no vertical stiffness and each horizontal frame withstood its own water pressure.

All the frames except the six upper ones were designed to have a maximum stress of +10,000 pounds per square inch under the action of water pressure alone; and the six upper frames are all made like the seventh.

Then the abscissas of the broken line *e d b c* represent the deflections which the miter post would have if all the frames were loaded in such a way that the maximum stress would be 10,000 pounds per square inch.

It will be seen that the curves of theoretical deflections pass beyond the line *e d b c* in two places.

When there is perfect contact at the sill the horizontal frame at a point 46 feet above the sill may be stressed to more than 10,000 pounds per square inch, and likewise with frames near the bottom when there is no contact at the sill.

In neither case is the deflection more than 8 per cent greater than that corresponding to a maximum stress of 10,000 pounds per square inch.

Considering stress proportional to deflection, the maximum stress in these two cases will be only 10,800 pounds per square inch, which is certainly not serious.

Knowing the loading on the vertical system, the maximum bending

moment may be readily found. The maximum stress $f$ of the vertical beam is found by the formula:

$$f_1 = -\frac{2\ y_1\ M}{I}$$
$$f_2 = +\frac{2\ y_2\ M}{I}$$

in which $y_1$ and $y_2$ are the distances from the neutral axis to the extreme edges of the vertical beam. M is the maximum bending moment which evidently occurs when there is contact at the sill.

The stress is double that given by the usual formula, since the deflection at the miter post is twice the mean deflection.

Determining M, $y_1$, and $y_2$ and substituting, we have:

$f_1 = -17{,}700$ pounds per square inch.
$f_2 = +16{,}000$ pounds per square inch.

This may seem rather high, but there is no danger of rupture, for, unlike the ordinary beam, if the deflection increases beyond that which causes this stress the beam is immediately relieved of its loads.

Fig. 2, plate 80, illustrates the case of the upper gate of an 80-foot lock for 21-foot channel, which is the lowest gate that has been designed. *a b* represents the deflected position of the miter post if the gate has no vertical stiffness.

As it is a straight line, it is also the position of the miter post if there is no contact at the sill, no matter what the vertical system may be.

*o c* represents the position of the miter post if the gate has vertical stiffness and there is contact and no deflection at sill.

*b d* represents the position of miter post when all horizontals have a maximum stress of 10,000 pounds per square inch.

As this line falls outside of all others, we may be reasonably certain that in no horizontal is the stress greater than 10,000 pounds per square inch.

Fig. 3, plate 80, shows the behavior of an upper gate of 80-foot lock for 30-foot channel, with 10-foot flood water. This gate receives the highest pressures of any for which timber bearings in the quoin and miter posts are proposed.

The line *a b* represents the deflected position of the miter post if there were no vertical stiffness.

*c d* represents the deflected position of the gate with vertical stiffness and no contact at the sill.

*o e* represents the deflected position of the miter post with vertical stiffness and contact at the sill.

*b f d* represents the deflected position of the miter post when the maximum stress is 10,000 pounds per square inch. This line lies well outside all others, as in the previous case.

At first thought it might be expected that the line *b f d* would be vertical for the whole height of the gate, inasmuch as it represents a condition of uniform stress in the steel.

The section of the timber in the posts, however, is not, as in the case of the steel, proportional to the pressure upon it; hence the inclination of the line *b f*.

Fig. 4, plate 80, is for a gate between the 80-foot locks of the Lewiston flight. These locks have 31 feet depth of water on sill and a lift of 40 feet, with a flood at times of 6 feet.

The gates may therefore be required to withstand a head of 77 feet of water.

*a b c* is the line of deflection of miter post if there is no vertical stiffness.

*d c* is the line of deflection of miter post under a maximum stress of 10,000 pounds per square inch.

*o e* is the line of the deflected miter post with contact at sill.

This line passes outside of *d c*, indicating that the maximum stress in the horizontals at that point is more than 10,000 pounds per square inch. The maximum excess is only 8 per cent, making the maximum stress only 10,800 pounds per square inch.

The comparison of figs. 1 and 4 shows the influence of the wood upon the deflection, as both are drawn to the same scale, and *b c* fig. 1 and *b c* fig. 4 would have the same abscissas if it were not for the presence of the wood.

These four cases represent the extremes of all the gates designed.

The above method is purely theoretical, and as all theoretical analyses are liable to be in error, it was thought very desirable to obtain a check upon the results by actual measurement of the behavior of large steel gates.

With this end in view, a series of measurements were made upon the gates of the Poe lock at Sault Ste. Marie, Mich.

These measurements were made by Mr. Henry Goldmark, assisted by Messrs. Joseph Ripley and B. Rohnert, United States assistant engineers, and Messrs. C. M. Ayres, and H. C. MacNaughton, in June, 1898, and April, 1899.

The following, quoted from Mr. Goldmark's report upon the measurements, described the gates and method of measurements:

> The lock has a clear width of 100 feet, with a depth of water on sill of 21 feet. The total height of the lower gates is 43 feet, and the average lift of lock is 19 feet. The mitering angle is 21° (rise of about one-fifth). The leaves are of soft steel and curved in plan, forming a continuous arch when closed, and are sheathed on both sides. The distance between sheathing plates is 30 inches at the quoin and miter posts and 36 inches at the middle of the leaf. Their thickness varies from three-eighths inch to one-half inch. The frame consists of six horizontal arches spaced uniformly 30 inches between centers and of seven vertical frames, besides the quoin and miter posts. Four of the vertical frames extend only halfway up from the bottom of the gate.

None of the vertical frames are continuous, except through the riveted connections.

The pressure at the quoin is transmitted through a continuous flat steel plate 10 inches wide, bearing directly against the cut stone. At the miter posts the contact is through oak timber with 12-inch faces.

To determine the deformation of these gates, the following quantities were measured:

(*a*) The change in the versed sines of the two gates considered as a continuous arch between the hollow quoins. This is equivalent to the movement of the miter posts parallel to the axis of the lock.

(*b*) The corresponding movements of points at the middle of each leaf.

(*c*) The change in the versed sine of each leaf.

(*d*) The change in the length of the chord connecting the quoin and miter post.

All measurements were made for each horizontal frame down to the lower level.

The changes in the chord and versed sines of the separate leaves are small and difficult of determination, hence the measurements (*a*) and (*b*) give more satisfactory results than those marked (*c*) and (*d*).

The method used in determining the movement of the miter posts and the points at the middles of the leaves may be readily understood by reference to fig. 18, which shows ground plans of the gates and lock walls, in which A and B are points in the gates whose movements are to be measured. They were marked by prick punches.

$I_1$, $I_2$, $I_3$, $I_4$, are points on the lock walls at which transits were set up.

I M, I N, are base lines parallel to the axis of the lock on the top of the lock walls.

$M_1$, $M_2$, are points at each base line in which it is intersected by a vertical plane passing through the center of the transit and the point A.

$N_1$, $N_2$, are the corresponding intersections for points B.

The successive steps in the measurements were the following:

The gates were first carefully closed so as to get a symmetrical mitering, and the locks filled to the level of the upper pool. The transits were then set up at $I_1$, $I_2$, etc., the points of intersection M, $M_1$, determined (both by direct foresight and after double reversing the instrument), and the lengths I M measured with steel tapes laid flat on the lock walls. These measurements were taken consecutively for all points A on the different horizontal frames.

The water in the lock was then allowed to run out until it stood about 1 foot higher than in the lower pool. A further lowering it was found was liable to cause the gates to open. The new positions of all points A were then determined by finding the points of intersection M with the same base line and measuring the new distance I M, etc.

The complete series of measurements was, of course, made in every case without opening the gates or changing the miter, so that the deflections obtained are believed to be true elastic deflections due to stress in the material due to water pressure acting against the gates.

Two transits were used, one at each wall, merely in order to save time, as the work of each instrument was entirely independent.

The measurement for the points marked B were made in exactly the same way as explained for the points A.

The actual horizontal movements of A and B, parallel to the axis of the lock, were obtained by simple proportion from the geometric figure and the measured distance I M and I N.

The above describes the measurements made in June, 1898. At this time observations on the gate could be made only above the lower pool.

# ST. MARYS FALLS CANAL.

## Poe Lock — Lower Gate.

General Plan showing Method of measuring Deflections.

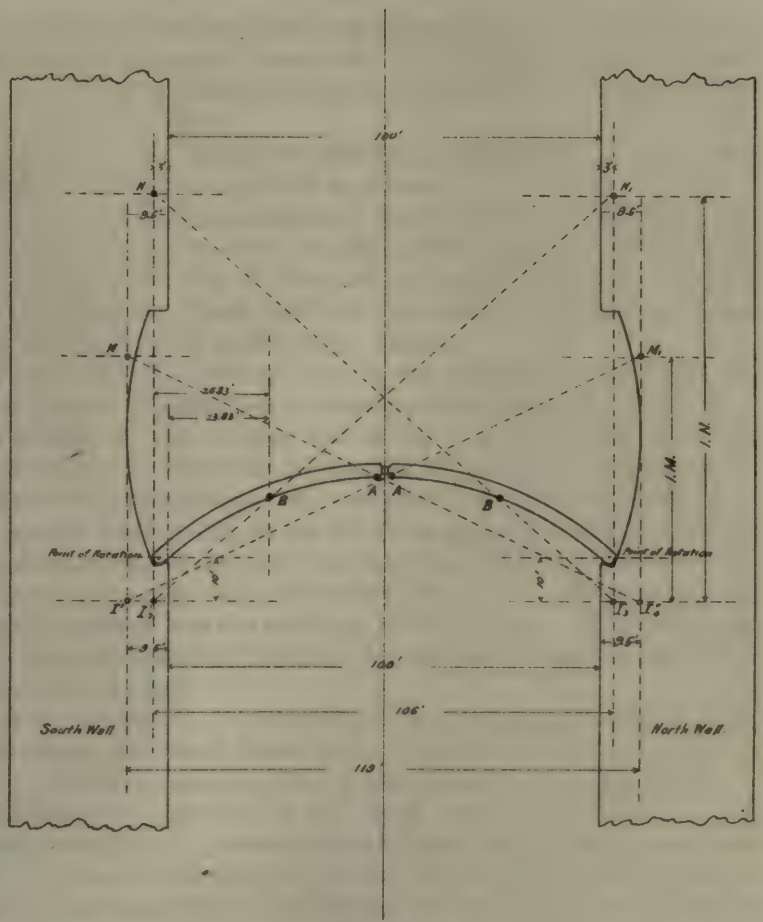



*Fig. 18.*

JULIUS BIEN & CO. PHOTO LITH.

In the measurements made in April, 1899, the lower guard gate was closed and the space between it and the lower lock gate was pumped out. The lock was then filled to various stages, and at each stage of water a complete set of observations was made, using the same methods as described above.

The measurements made at this time included those designated above as (*a*), and a measurement of the compression of the wood, which was accomplished by lowering a man from the top of the gate in such a way that he was able to measure the distance between the prick-punch marks AA at each horizontal frame for each stage of water.

In both 1898 and 1899 very satisfactory results were obtained, except those designated above as (*c*) and (*d*). The changes to be measured in these cases were so slight that they could not be accurately determined by the means used.

The results of the measurements are very uniform. Two cases which are typical of them all will be given.

Fifteen and one-half feet depth of water on the upper side of the gate and no water on the lower is called water stage A; 37 feet depth of water on the upper side of the gate and no water on the lower is called water stage B; 8 feet depth on the upper side of the gate and no water on the lower is called water stage C.

The abscissæ of the broken line in fig. 5, plate 80, represent the measured change of deflection in passing from stage A to stage B.

The abscissæ of the broken line in fig. 6, plate 80, represent the measured change of deflection in passing from stage C to stage B.

The theoretical deflections were computed in the same manner as in the example worked out on the previous pages by substituting the proper values in equations (32). In this case, however, there is a deflection at the sill, as is evident from figs. 5 and 6. Unfortunately, the lowest arch observed was the one next to the bottom. Extending the probable curve of deflection down to the bottom, we get for the deflection at the sill 0.24 inch.

Solving the equations and substituting in equations (25), the theoretical deflections are found which plot into the curve shown in fig. 5, plate 80. The curve shown in fig. 6 is obtained in the same way.

The modulus of elasticity of the wood was determined from the computed intensities of pressure at the miter and the measured compression. It was found that the timber below the level of the lower pool, which was immersed at all times, had a very uniform value of 20,000 as a modulus of elasticity, while that above the lower pool had a modulus of about 30,000.

The agreement of the theoretical deflections with those actually measured is as close as can be expected and is very strong evidence that the theoretical results deduced for the gates designed are fair approximations to the truth.

There are three factors in the computations that are necessarily somewhat indefinite. They are the moment of inertia of the vertical girder, the deflection at the sill, and, if timber bearing blocks are used, the modulus of elasticity of this timber.

To be on the safe side, the first should be taken large and the second and third small.

It is impossible to say how much the effective moment of inertia will be reduced by buckling of the skin plates and defect of the riveted joints. If it be taken at the value it would have if all verticals of the gate formed one solid piece, then the results will be on the safe side, as the greater the vertical stiffness the greater will be its effect.

The value of K, or the deflection at the sill, depends upon the manner of placing the sill timbers. It is probably on the safe side to take K=0, as the sill timber will compress considerably under the pressure which it will be required to withstand.

If timber is used, it will be well saturated at all times, and its modulus of elasticity or compression will be small. In the computation, the lowest value obtained from the measurements on the locks at Sault Ste. Marie was used.

The simultaneous equations are easily solved by the aid of the slide rule.

Mr. Henry Goldmark has worked out this problem, using the method of "least work." In his analysis he has made the same general assumptions as have been made in the foregoing analysis, and, as should be expected, his method gives the same results.

## SHEATHING.

The resistance of plates, supported at their edges, to forces normal to them is not well understood. No satisfactory theoretical analysis of their stresses has been made. The designer must rely upon empirical formulæ, derived from the results of experiment, to guide him in the proportioning of sheathing plates.

The most recent well-conducted series of experiments upon large test plates are those of Prof. C. Bach, of Stuttgart.

From the results of these tests formulæ were derived which are probably the most reliable of any in use.

For flat rectangular steel plates, acted upon by fluid pressure, Bach's formula is:

$$t = cb\sqrt{\frac{p}{1+\left(\frac{b}{a}\right)^2 f}} \quad \ldots\ldots \quad (34)$$

in which

$t$ = the thickness of the plate.

$c$ = an empirical factor, depending upon the manner in which the edges of the plate are held.

For a plate fixed at the edges $c = 0.61$,

$a$ = length of plate between supports.

$b$ = breadth of plate between supports.

$p$ = intensity of fluid pressure.

$f$ = maximum allowable tensile stress in the metal.

This formula was used to determine the thickness of the sheathing plates for all gates. The results were checked by various other formulæ in general use.

No plates less than three-eighths inch thick were used and none more than one-half inch thick were required.

The sheathing plates are proportioned by the flat plate formula, although they are in reality curved and thereby derive considerable additional strength from arch section.

## PIVOT.

Details of the pivots which are proposed for use are shown in figs. 15, 16, 17, 18, and 19, plate 70; figs. 10, 11, 12, and 13, plate 71, and figs. 9 and 10, plate 74.

The pivots are all of the same general design, although a difference is made in the shape of the castings in upper and lower gates on account of the difference in the sill contact.

The bearing is bronze upon polished steel. This combination has a low coefficient of friction, especially when working in water. The bearing parts move very slowly one upon another, the maximum rate of speed being only 0.02 foot per second.

A cast-steel base embedded in the concrete floor of the lock holds the pivot proper, which is a steel forging hemispherical on top.

Bolted to the gate is another casting which holds a bronze bushing or hollow hemispherical cup which fits the pivot. The pivot is proportioned to take both the weight of the gate and the horizontal thrust.

## UPPER HINGE.

The details of the upper hinge are shown in figs. 11 and 12, plate 70.

The force acting at the upper hinge is:

$$H = \frac{a}{h} W$$

In which, W = weight of one leaf of gate.

$a$ = distance from center of gravity of gate to vertical through pivot center.

$h$ = distance between upper hinge and pivot.

In this formula, as the height of the gate increases the weight increases in nearly the same ratio. The pull upon the upper hinge does not differ greatly between the lightest and heaviest gates designed. As an example, H for the lower gate for a lock of 40-foot lift is only 15 per cent more than for the lower gate for a lock of 5-foot lift. For

this reason little change is made in the anchor bars, and none at all in the castings for the different gates.

The anchorage consists of eyebars extending back in the masonry to beams embedded in the concrete. Sufficient masonry is embraced to preclude any danger of movement.

The angle between the anchor bars is slightly greater than that through which the gate swings, and they are so placed that both are always in tension, thus avoiding reversal of stress and the consequent danger of loosening and play of the parts.

Provision is made for adjustment by means of wedge-shaped keys.

The castings are of steel and proportioned for a very low unit stress. The anchor bars are also proportioned very liberally, to provide for any reduction of section which is likely to occur from rusting.

### SILL CONTACT.

For the lower and intermediate gates the sill contact is made, as shown on plate 71, by bolting to the flange of the lower horizontal frame a straight timber bearing piece which closes against a straight timber sill.

When the gates are closed a head of water equal to the difference of level of the two sides of the gate acts upon the bottom of the gate, tending to lift it. This lifting effort upon the lower gates is but slightly greater than the weight of the gates themselves, so that the friction of the quoin posts in the hollow quoins will overcome all tendency to upward movement. The coefficient of friction required to do this is only about 2 per cent.

On account of this upward pressure upon the bottom of the gate, numerous web stiffeners are placed upon the bottom frame, and its lower flange is strengthened by a plate extending to the flange of the frame above.

If the upper and guard gates and gates between locks of a flight should expose so great a bottom area as this to maximum water pressure, the upward lift would be far in excess of the weight of the gate. To meet this difficulty the bottom frame of these gates is made very much narrower than the others and no timber bearing piece is used. Instead, the heavy steel flange angle is finished and bears against the sill. This arrangement is shown on plate 70.

The lower frame is attached to the one above at intervals by cast-steel brackets.

A curved sill is required for these gates.

### FOOTBRIDGE.

For the convenience of the workmen and others, a footbridge is provided upon the top of the gate. It has a railing which is removable and built in short sections, so that one man can handle a section.

ESTIMATES.

In connection with the estimates, it is appropriate to review briefly the conditions which prevail in the structures.

The gates are of steel, with horizontal framing. The spaces between the frames are variable, being 3 feet 3 inches near the top and less than 2 feet near the bottom of the highest gates.

The frames are straight on the downstream side and curved on the other; their breadth is 4 feet in gates for 60-foot locks and 4½ feet in gates for 80-foot locks. They are proportioned under the assumption that the center of pressure at the miter may have a range of position 8 inches each side of the center of the bearing face. The maximum stress in the frames is 10,000 pounds per square inch. The maximum stress in the sheathing is 15,000 pounds per square inch. The minimum thickness of metal is three-eighths inch. The minimum angle used is $3\frac{1}{2}\times3\frac{1}{2}\times\frac{3}{8}$ inches. Diameter of rivets $\frac{7}{8}$ and $\frac{3}{4}$ inch.

Detailed designs and careful estimates of the weight of gates for about one hundred and twenty-five different cases were made. These comprised single and double skin, upper and lower gates for 60, 65, and 80-foot locks for a 21-foot and 30-foot channel, and lifts varying from 0 to 50 feet.

The estimated weights of the rolled steel in the lower gates are plotted on plate 79. Abscissas are the lifts of the locks and ordinates are the weights of structural steel in one leaf of the gates.

To each diagram shown, a parabolic curve is fitted as shown on plate 79. The ordinates of the computed points, with two exceptions, do not differ more than 2 per cent, and in these cases not more than 3½ per cent, from the ordinates to the parabolic curves; therefore, if the weights of the gates for a lock of any lift between 0 and 50 feet be read from the curve, they will be within the practical limits of accuracy for structural steel work.

The general equation of these parabolic curves is:

$$W=AH^2+BH+C \quad . \quad . \quad . \qquad (35)$$

in which W is the net weight in pounds of the structural steel in one leaf of the lower gate of a lock, the lift in feet of which is H. A, B, and C are constants dependent upon the width of the lock and depth of water on sill.

The equations of weight of lower gates for 80 and 60 foot locks are—

For 80-foot lock, 30 feet depth of water on sill, $W=85H^2+3600H+130000$.

For 80-foot lock, 21 feet depth of water on sill, $W=83H^2+3010H+103000$.

For 60-foot lock, 30 feet depth of water on sill, $W=38.85H^2+3009H+106500$.

For 60-foot lock, 21 feet depth of water on sill, $W=38.76H^2+2713H+80500$.

The weight of a lower gate for any particular width and lift of lock, but of varying "depth on sill," may be written: $W=K+CD$, in which K represents the weight of that part of the gate above the surface of the lower pool plus that part below the top of the sill, and C is the weight per vertical foot of that part of the gate between the surface of the lower pool and the sill, and D is the depth in feet of the water on sill.

It is evident from the nature of the design that this form of equation is correct, because the water pressure per vertical foot upon the gate below the lower pool is constant, and therefore the horizontal frames, their spacing, the quoin and miter posts, the verticals and sheathing are all uniform from the surface of the lower pool to the sill.

Making A, B, and C linear functions of D and determining constants, we have—

For 80-foot lock $W=(78.33+.222D)H^2+(1633.5+65.55D)H+(40000+3000D)$ . . . (36)

For 60-foot lock $W=(85.55+.01D)H^2+(2022.6+32.88D)H+(19860+2888D)$ . . . (37)

These are the equations of the two series of curves shown on plate 79.

These formulæ and curves apply to upper and guard gates as well as to lower gates.

H is to be taken as the maximum head of water acting upon the gate. For lower gates this is the maximum lift of the lock.

In the designs all upper gates were proportioned the same as guard gates.

By the use of either the equations or the curves the weight of structural steel in one leaf of a gate within limits previously mentioned may be found. To this must be added the material in pivot and upper hinge details, given on plate 79.

These are the equations which are especially intended for use in making the estimates of the gates for the locks of the various deep waterway routes investigated by the Board. Twenty-one and 30-foot channels only are proposed for the deep waterway, yet the depth of water on sill varies widely for different cases on account of varying flood water and other local conditions; otherwise the diagrams, fig. 1 on plate 79, might be used to get the weight of the gates.

The curves on plate 79 were used to make the estimates for all the gates for the proposed deep waterway, except those between locks of a flight. These estimates are included in the general estimates, which may be found in the reports of the various assistant engineers.

The gates between the locks of a flight are made the subject of special detailed estimate, since they do not come within the limits of $H=0$ and $H=50$. In the flight of 40-foot lift locks H is as great as 77 feet.

The principal object of all the work done upon the subject of lock gates was attained when equations (36) and (37) were developed and estimates for the proposed work had been obtained from them. As a matter of general interest, however, the work was carried somewhat further.

Numerous diagrams were plotted, weights of gates being ordinates and widths of locks being abscissas. The lift of lock and depth of water on sill remained the same for each diagram. It was found that the points plotted in these diagrams fitted parabolic curves, or, in other words, for any given lift of lock and depth of water on sill:

$$W = E\,b^2 + F\,b + G \quad . \quad . \quad . \quad . \quad (38)$$

in which $b$ is the width of the lock and E, F, and G are certain constants depending upon the lift of lock and depth of water on sill.

This might have been expected, since certain parts of the gate, such as the flanges of the horizontal frames, increase as the square of the span and certain other parts of the gate, such as the sheathing, increase directly as the width, and certain other parts, such as the posts, do not vary at all.

The three equations representing the weight of single skin gates for 60, 65, and 80 foot locks, with 30-foot depth of water on sill, are:

80-foot lock, 30-foot depth on sill $W = 85\,L^2 + 3600\,L + 130000$
65-foot lock, 30-foot depth on sill $W = 47.12\,L^2 + 3250\,L + 109700$
60-foot lock, 30-foot depth on sill $W = 38.85\,L^2 + 3009\,L + 106500$

The only form of equation that will satisfy the conditions of both equations (35) and (38) is:

$$W = (d b^2 + e\,b + f)\,H^2 + (g b^2 + h\,b + k)\,H + (j\,b^2 + m\,b + n) \quad . \quad . \quad (39)$$

in which any constant may vanish. We now have:

$$6400\,d + 80\,e + f = 85$$
$$4225\,d + 65\,e + f = 47.12$$
$$3600\,d + 60\,e + f = 38.85$$

from which we have $d = .0436$ $e = -3.796$ $f = 109.65$. In like manner, $g$, $h$, $k$, $j$, $m$, and $n$ may be found and substituted in the general equation (26). We then have the general equation for the weight of one leaf of a single skin gate for varying widths and lifts, but for a constant depth of water on sill of 30 feet:

$$W = (.0436b^2 - 3.796b + 109.65)\,H^2 + (-1.243b^2 + 203.5b - 4725)\,H + 35.666b^2 - 3818b + 207200.$$

Proceeding in the same way with the gates for 21 feet depth on sill, we have for the weight of one leaf:

$$W = (.0388b^2 - 3.22b + 92.28)\,H^2 + (-.703b^2 + 113.3b - 1553)\,H + 15b^2 - 975b + 85000.$$

As before, we know from the nature of the design that the weight of a gate is a rectilinear function of D, the depth of water on sill. We may, then, combine the above equations into a general equation giving the weight of a single skin gate for any depth of water on sill, width and lift of lock within limits.

We then have:

$$W = [(.000533D + .0276)b^2 + (-.064D - 1.876)b + 1.93D + 51.75]\ H^2 + [(-.06D + .557)b^2 + (10.022D - 97.16)b - 352.44D + 5848.3]\ H + [(2.296D - 33.215)b^2 + (-315.89D + 5658.6)b + 13577D - 200100].$$

In which

W = the weight in pounds of the structural steel in one leaf of a single skin mitering gate with horizontal framing, straight on the downstream side.

$b$ = the breadth of the lock in feet.

H = the maximum head in feet of water acting upon the gate.

D = the depth on sill, or depth in feet above the top of the sill of the water on the downstream side of the gate when head H acts.

In the same manner the equation giving the weight of double skin gates was developed:

$$W = [(.00053D + .0276)b^2 + (-.064D - 1.876)b + (1.93D + 51.75)]\ H^2 + [(-.06D + .3833)b^2 + (10.033D - 68.71)b + (-353D + 5107)]\ H + [(2.044D - 29.6)b^2 + (-274.67D + 5121.47)b + (12333D - 179600)].$$

The caution may be again repeated that these equations are empirical and should not be used outside of the limits of the data from which they were derived; that is, they should not be used for values of L greater than 50 feet, nor for $b$ greater than say 85 feet, nor less than say 55 feet. From the nature of the design, D may be almost anything.

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A standard German work on hydraulic engineering. Contains an historical account of the development of locks and a description of the details of small gates as built in different countries.

Of larger gates, the following are described and in part illustrated by plans, viz:

Cherbourg Harbor. Width of lock equals 55 feet. Timber gates built near the beginning of this century.

Coburg dock, Liverpool. Width of lock equals 68 feet. Timber gates.

Canal lock, near Mulhouse (Alsace), 17 feet wide. These were the first wrought-iron gates built on the Continent (1845).

Bremerhafen docks, 1848. Width of lock equals 76 feet. The first large wrought-iron gates built in Germany.

Geestemünde docks. Width of lock, 74.68 feet. Wrought-iron gates, built in 1861.

Willem III lock (Holland). Wrought-iron gates, built in 1861–1865. Width of lock equals 58 feet.

Charenton lock, France. Small wrought-iron gates. Built in 1865. Width of lock equals 25.5 feet.

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Latest German treatise on hydraulic engineering. The chapter on locks is written by the designer of the lock gates on the North Sea—Baltic Canal.

It contains a very full discussion of the entire subject, including the theory of stresses and many detailed plans.

The following large gates are described and illustrated:

Canada docks (Liverpool): Timber gates, built 1853–1858. Width of lock equals 100 feet.

Transatlantique docks (Havre): Timber gates, built in 1862. Width of lock equals 100 feet.

Antwerp docks: Timber gates. Width of lock equals 80 feet.

Willemsvord docks (Holland): Wrought-iron gates.

Amsterdam Ship Canal: Wrought-iron gates. Width of lock equals 59 feet.

Geestemünde docks: Wrought-iron gates. Width of lock equals 74.68 feet.

North Sea, Baltic Canal: Steel gates. Width of lock equals 82 feet.

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Standard French treatise. Has a detailed discussion on lock gates, including the theory of stresses as based on Chevallier's experiments and Lavoinnes's mathematical investigations.

Description and plans of the following large gates:

Havre (Transatlantique docks): Timber gates. Width of lock equals 100 feet.

Dunkirk dock: Timber gates. Width of lock equals 68.9 feet.

Dieppe Duquesne dock: Timber gates. Built in 1869.

Fecamp docks (compound gates of timber and iron): Width of lock equals 54.1 feet.

Boulogne docks (iron gates): Built in 1866. Width of lock equals 68.9 feet.

Amsterdam Ship Canal (iron gates): Built in 1874. Width of lock equals 59 feet.

P. Guillemain. Navigation intérieure. Rivieres et Canaux. (Encyclopédie des Travaux Publics) Paris. (Baudry et Cie) 1885. Tome II, p. 32 to 97. Chapter on lock gates.

The general subject is discussed and many small wooden gates are illustrated and described.

The most valuable feature of this book is the account given of the author's experiments with models, showing the effect on the distribution of pressures of spacing the horizontal girders in a gate in various ways.

A mathematical theory is also developed by which the loading on each horizontal can be approximately obtained.

F. Laroche. (Ports Maritimes.) (Encyclopédie des Travaux Publics.) Paris. (Baudry et Cie) 1893. Tome I, p. 185. Chapter on lock gates.

This treatise gives the general theory rather than special designs.

In the appendixes, detailed calculations of the stresses in two gates are given, one of them based directly on Chevallier's experiments with models and the other on Lavoinne's formulæ for the distribution of stresses.

C. Colson. Notes on docks and dock construction. London (Longmans, Green & Co.), 1894.

This book gives the views of an experienced engineer on various topics rather than a systematic exposition. In the chapter on lock gates, various mooted questions in gate design are taken up from a practical standpoint.

Plans of the following gates are given:

Dunkirk docks (wrought iron): Width of lock equals 69 feet.

Amsterdam Ship Canal (wrought iron): Width of lock equals 59 feet.

Avonmouth docks: Timber gates. Width of lock equals 70 feet.

Whitehaven docks: Timber gates. Width of lock equals 50 feet.

Barry docks: Wrought iron. Width of lock equals 80 feet.

San Fernando docks, Buenos Ayres: Wrought iron. Width of lock equals 64 feet.

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Drawings of the timber gates for the Great Grimsby dock (width of lock equals 70 feet) and of the wrought-iron gates in the Victoria dock, London (width of lock equals 80 feet), are given.

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*Wrought-iron gates.*—Brooklyn Navy-Yard, 1847, width of lock equals 60 feet; Victoria docks, London, 1857. width of lock equals 80 feet; Jarrow docks (Tyne), 1858, width of lock equals 80 feet; Limehouse docks, width of lock equals 60 feet; Surrey docks, width of lock equals 50 feet; Boulogne docks, 1867, width of lock equals 68.9 feet; Havre docks, 1871, width of lock equals 52.5 feet.

This essay covers the ground very well up to 1872. The series of articles on dock gates published in The Engineer in 1873 are practically a translation of this paper.

Harry F. Hodges. First lieutenant, Corps of Engineers, United States Army. Notes on Mitering Lock Gates. Washington, Government Printing Office, 1892, 132 pages, 7 plates. (Professional Papers of the Corps of Engineers, United States Army, No. 26.)

This is one of the best papers on lock gates. It treats very fully of the stresses in all the members and develops a practical method for correct designing.

Plans of the following gates are given:

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1888. I Semestre, page 1018. Laroche. Méthode élémentaire pour calculer la résistance des portes d'écluse. (Elementary investigation of stresses. Not very valuable.)

1889. I Semestre, pages 5–97. Desprez. Le Bassin Bellot. (Excellent plans and description of iron gates for a lock 98.4 feet wide.) Also published in book form.

1892. I Semestre, pages 633–801. Maurice Widmer. Canal du Havre à Tancarville. (Excellent plans and calculations for wrought-iron gates for lock 52½ feet wide.)

1892. II Semestre, page 783. A. Fontaine. Les Écluses à grande chute (5.2 m.) du Canal du Centre. (Interesting small gates with buckled steel covering.)

1893. II Semestre, page 44. Maurice Renard. Nouvelles écluses du Canal St. Denis. (Single skin gates for lock 27 feet wide, with 32½ feet lift, small but interesting.)

1895. I Semestre, pages 459–602. C. de Franchimont. Note sur la construction du 3 eme bassin a flot du Rochefort. (Excellent account of gates and machinery. Reasons for preferring "horizontal" system of girders.)

MEMOIRS DE LA SOCIETE DES INGENIEURS CIVILS.

1872. Pages 319–415. Sylvain Périssé. Étude sur les portes d'écluse a lar Mer en France et en Angleterre. (Excellent essay on dock gates. Reprinted as a book. Paris, 1873.)

PORTEFEUILLE ÉCONOMIQUE DES MACHINES.

1883. July, page 102. Appareils de Manoeuvre des portes et des ventelles des écluses double du Canal du Nord sur Paris. (Plans and description of operating machinery and valves for small locks.)

TRAVAUX DE VACANCE (ÉCOLE CENTRALE).

Port du Havre. Porte d'écluse gome Bassin. (Two sheets of illustrations: no text.)

ZEITSCHRIFT DES HANNOVERSCHEN ARCHITEKTEN UND INGENIEURVEREINS.

1852–53, page 339: 1853–54, page 241. Ruhlmann. (Short mathematical study on most economical sill angle. No special value.)

1855, page 475. H. Huebbe. Details of timber gates for Great Grimsby Lock, 70 feet wide.

1861, page 93. Plener. Great Western Dock gates at Plymouth (England). Plans and description of wrought-iron gates for lock 80 feet wide.

1865, page 226. Welkner. Wrought-iron gates for Geestemünde Docks. Width of lock equals 76 feet. Valuable experiments on strength of flat plates.

1865, page 491. Interesting historical note on wrought-iron gates.

1866, page 309. Hess. Bemerkungen uber die neuen belgischen und franzosischen Konstruktionen der Kanal Schleusenthore.

1838, page 419. Professor Barkhausen. "Uber einige neuere Englischen Seeschleusen." Excellent notes and sketches on modern English locks.

1889, page 743. Van Horn. Plans of gates for Transatlantique Dock, Havre. (Taken from Annales des Ponts et Chaussees, 1887.)

1891, page 349. E. Rechtern and H. Arnold. Der Bau der zweiten Hafeneinfahrt zu Wilhelmshafen. (Good plans and descriptions of wrought-iron gates for lock 80 feet wide. Reason for preferring girder to arch shapes.)

DEUTSCHE BAUZEITUNG.

1891, September 12 and 19. L. Brennecke. Die Entwickelung der Schleusenthore der Neuzeit. (Brief but excellent statement of the author's views on lock gates.)

TIJDSCHRIFT KONINKLIJK INSTITUUT VAN INGENIEURS (HOLLAND).

1863–64, page 14. J. Strootman. Over wijde zeesluizen en sluitdeuren van plaatijzer. (Complete study on calculation and design of iron lock gates.)

1866–67, page 116. Strootman. Docks Willemoord. (Wrought-iron gates about 36 feet square.)

1870–71, page 187. J. F. W. Conrad. (Full description of Willem III lock, including plans of wrought-iron gates for a lock 59 feet wide.)

1885–86, page 429. J. Strootman. Ijzeren deuren voor sluizen op binnenlandsche scheepvaartskanalen. (Good theoretical study of small iron gates.)

Grateful acknowledgment is here made to Mr. Joseph Ripley, United States assistant engineer in charge of St. Marys Falls Canal, for valuable information freely given and assistance rendered in making measurements of the deflection of the lock gates at Sault Ste. Marie.

The work covered by this report was begun in December of 1897 by Mr. Henry Goldmark, assistant engineer, and remained under his charge until June, 1899. After his retirement on account of ill health, the undersigned, who had acted as principal assistant from May, 1898, completed the investigations and prepared the present report.

Very respectfully submitted.

S. H. WOODARD

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

APPENDIX No. 3.

## BREAKWATERS AT CANAL ENTRANCES, OSWEGO AND OLCOTT, N. Y.

### BREAKWATERS AT CANAL ENTRANCES.

The plans of the Board of Engineers on Deep Waterways provide for canals entering Lake Ontario at Oswego and Olcott, N. Y. I have the honor to submit for the consideration of the Board the following projects for the construction of breakwaters at these entrances, with estimates of cost. The breakwaters first considered are adapted to the requirements of a waterway having a depth of 30 feet.

### OSWEGO.

The existing harbor at this locality is situated at the mouth of the Oswego River, near the eastern end of Lake Ontario. The prevailing violent winds are from the west and northwest. The greatest water exposure is to the westward, which is therefore the direction of the heaviest seas. The movement of gravel and other material derived from the attrition of the shores is from west to east. The material of the bottom is sand and gravel underlaid by argillaceous sandstone of the Utica formation.

The construction of breakwaters to form an anchorage and cover the entrance to the Oswego River was commenced by the Government in 1827, and works of extension or repair have been in progress down to the present day. The existing breakwaters are of the usual crib formation so long employed in the construction of such works for the improvement of the lake harbors. Their locations are shown on plate 18.

The proposed canal, as designed by the Board, enters the lake at Sheldons Point, which is a short distance west of the existing breakwater harbor. The first lock is located on the shore of the lake. The channel connecting it with deep water in the lake will be about 1,700 feet long and 600 feet wide, and is to be bordered by timber cribs for mooring and guiding vessels, as shown on figures 1 to 6, inclusive.

### PLAN OF THE BREAKWATERS.

The breakwaters required at this locality have for their objects to shelter the entrance to the canal from heavy seas, to protect the excavated channel from shoaling from the movement of materials worn from the shores, and to form a harbor of refuge for vessels in time of storms. The heaviest seas come from the westward. The main breakwater is therefore located west of the canal and extends in a northerly direction, following the arc of a circle, with 4,700 feet radius, in order to increase the anchorage area. This direction has been selected so as to be about normal to the direction of the most

violent wave motion, so as to avoid the formation of an accumulated wave. The long breakwater in the existing harbor has a northeast direction, and makes so small an angle with the direction of greatest wave motion that an accumulated wave is formed at its eastern end during the prevalence of westerly storms, making entrance to the harbor difficult and dangerous.

The main breakwater commences at the shore, and therefore serves as a jetty to stop the eastward movement of material which might form shoals in the excavated channel.

Since northerly winds sometimes create heavy seas in this locality, a second breakwater has been designed to extend from a point on the face of the old breakwater, in a northeast direction, toward the eastern extremity of the main breakwater. The interval between the outer ends of these breakwaters, which has a width of 950 feet, forms the entrance to the harbor.

It will be observed that these breakwaters are located, with reference to each other, so as to leave between their ends a clear channel 600 feet wide, measured perpendicular to its axis, which curves with a radius of 5,000 feet from the entrance to a point between the heads of the piers. The tangent to the axis of the channel at the entrance has a direction about north. The shelter could be increased by extending the western breakwater farther to the eastward; but this would increase the curvature of the channel at the entrance, and is therefore considered undesirable.

The harbor thus formed will have an area of nearly 127 acres, measuring to the low-water line. The existing harbor, which has an area of about 180 acres, will always be available for the anchorage of vessels of small draft, and it can be made conveniently accessible from the new harbor by the removal of the breakwater at its western end. Large vessels entering the harbor will, of course, pass directly into the canal. It is believed that the mooring piers and the anchorage area in their vicinity will afford ample accommodation for those descending the canal and detained by storms. The aggregate length of the proposed breakwaters is 6,635 feet. Their locations are shown on figures 1 to 6, inclusive.

### CHARACTER OF STRUCTURES.

Heretofore the piers and breakwaters constructed in the Great Lakes have been formed of pile work or timber cribs filled with stone. When the exposure is great, crib breakwaters have been found preferable to those formed of piles. These structures are, to a certain extent, of a temporary character, and require frequent and troublesome repairs. Below the water level they may be considered permanent, if not displaced by storms, but above that level they require renewal every ten or fifteen years. The cribs require carefully prepared foundations, and when all precautions have been taken

it is not always possible to make them retain their places upon the bottom. Breakwaters thus constructed are, of course, much cheaper than structures formed wholly of concrete or stone masonry, but it is a question worthy of investigation whether they are as advantageous or as economical, considering the cost of maintenance, as random stone breakwaters constructed in accordance with modern methods, like those which have been established at certain localities on the coast of the sea.

The random-stone breakwaters adopted for the formation of harbors on our seacoast consist of a substructure formed by depositing stones along the site of the work to about the level of mean low water, and of a superstructure constructed of heavy stones laid carefully in position. The characteristic advantages of such breakwaters, as compared with those of other types, are the facility and simplicity of their construction and repair. Their peculiar disadvantage is that they require a large volume of material in the substructure, most of which is not needed to resist wave action and serves only to support the comparatively small resisting parts of the work. In the locality under consideration random-stone breakwaters will, of course, be much easier to construct than crib breakwaters. They require no leveling under water, they are composed of only one kind of material, and the plant and method of construction are of the simplest character. The experience of the breakwaters at the entrance to Delaware Bay appears to show that works of this character, when properly constructed, have sufficient stability to resist the action of very violent storms. The injuries inflicted upon crib breakwaters by storms and ice are of a very troublesome character. The cribs slide on their foundations or tip over, the timber and iron parts are twisted and broken, and the filling is washed out. These works require constant attention and frequent expensive renewal or repairs. The injuries inflicted by storms on the breakwaters in Delaware Bay have, on the contrary, been of the most trifling character and easily repaired at very small cost. It only remains to compare the cost of construction of these two kinds of breakwaters.

At the time the method of crib construction was adopted for works in the Great Lakes lumber was cheap and plentiful and small stone suitable for filling could be readily obtained. On the other hand, economical plant and methods for quarrying, transporting, and depositing very large stones did not exist. The construction of random-stone breakwaters was at that time difficult and costly, the comparatively small size of the stone which could then be economically quarried and deposited gave to the works little stability, and it was considered absolutely necessary that the substructure should have a very large cross section with gentle slopes exposed to the action of the waves. Under these circumstances the adoption of the crib

method of construction was doubtless most economical and advantageous. At the present time the conditions are entirely different. The cost of lumber has greatly increased, while the cost of quarrying, transporting, and depositing large stone has greatly diminished. Moreover, experience in Delaware Bay and elsewhere seems to show conclusively that the cross section formerly adopted for random-stone breakwaters can be greatly reduced without sacrificing stability, if the work is constructed of large stone properly deposited.

Assuming that a crib should have a width not less than its height, it can easily be shown that, at present prices and with the depths at Oswego, a crib breakwater with the crib work carried nearly to the bottom would be much more expensive than a random-stone breakwater of the Delaware Bay type. There is, however, another method of construction in which cribs are employed which deserves careful consideration, and which is adopted in two of the breakwaters now in process of construction in Buffalo Harbor. These breakwaters consist of a random-stone substructure rising to a level of 22 feet below the water surface and a crib superstructure the top of which is 12 feet above lake level. The method is evidently modeled upon modern European practice, which carries the superstructure down to a level at which wave action is supposed to have no appreciable effect upon the substructure. The use of cribs instead of concrete in blocks or in mass is, of course, much more economical and can be safely adopted in the fresh water of the lakes.

In forming an approximate estimate of the difference in cost of breakwaters on the crib and random-stone methods at Oswego the following assumptions have been made:

1. The substructure for the crib breakwater will be formed of large rubblestone deposited upon the bottom. Its upper surface will be 22 feet below lake level and will have a width of 50 feet. The slopes will have an inclination of 1 on 1.3. Each cubic yard of substructure volume is assumed to require 1.34 net tons of stone.

At Buffalo a trench is excavated and filled with gravel to form a foundation for the work, as the hard bottom is covered with soft material of considerable depth. This is unnecessary at Oswego, where there is a hard bottom, and accordingly the cost of this part of the work is omitted from the estimate.

2. The superstructure will be the standard timber crib adopted at Buffalo. The cost of the timber and iron in 1 linear foot of this crib is estimated at $77.37, the cost of hemlock being assumed at $23 per M, white pine at $32 per M, and iron at 4 cents per pound. To this $1 is added to cover the extra cost of leveling the upper surface of the substructure under water. The assumed cost per linear foot of the superstructure without filling is therefore $78.37. The crib will contain 45.833 net tons of stone filling per linear foot.

3. The dimensions, method of construction, and estimated cost of the random-stone breakwaters are given in another part of this paper. The cost of the stone in place is estimated at $1.20 per net ton.

Under the above assumptions the difference in cost per linear foot between the random-stone and crib breakwaters for all depths greater than 22 feet is given by the formula

$$\triangle = 2.036D + 0.021D^2 - 94.88,$$

in which D is the depth and $\triangle$ is positive when the cost of the random-stone breakwater exceeds that of the crib breakwater.

At a depth of 34.4 feet the breakwaters of the two methods are equal in cost. This is almost exactly the average depth on the breakwater sites beyond the depth of 22 feet, so that the cost would be practically the same for the two methods. At depths less than 22 feet the random-stone method will be somewhat the cheaper. The cost of maintenance is, as before remarked, much less for random-stone than for crib breakwaters.

For the reasons above stated the random-stone method of construction described below has been adopted for the breakwaters proposed herein. It should be remarked, however, that in cases where it is desirable to utilize a breakwater for the purposes of mooring or unloading vessels, as at Buffalo, the crib superstructure should be adopted.

### METHOD OF CONSTRUCTION AND CROSS SECTION.

The method of construction and the cross section adopted for the works under consideration are based upon the results of experience in the construction of random-stone breakwaters at the entrance to Delaware Bay. The old breakwater harbor in that locality was commenced in 1828, and was completed in accordance with the original design in 1869. It was formed by two detached breakwaters separated by an interval of 1,390 feet. A new breakwater closing this interval was constructed between 1884 and 1898. Another extensive breakwater, to form a national harbor of refuge, was commenced in 1897 and is still in process of construction.

The methods followed in these works were first employed in the construction of the breakwater to close the interval in the old harbor. The history of this work is given in detail in the final report submitted to the Chief of Engineers on June 19, 1899, and published in the Annual Report of the Chief of Engineers for 1899, page 1346. The experience and reasoning upon which the method of construction is based will be found in this report, and it is therefore unnecessary to repeat them here.

*Substructure.*—This part of the work extends from the bottom to the level of low water. In construction it is best to raise it to a level of about 1 foot above low water to allow for settlement and to facil-

itate the construction of the superstructure. All the stone must be deposited within the limits of the low-water width, so that the mass may be permitted to form its own slopes under the action of the waves. The stones deposited to form the slopes should have a minimum weight of about 3 tons. For the interior smaller stones may be employed.

The most economical and rapid method of depositing the material, up to a level of about 10 feet below the water level, is from bottom-dumping barges. Above that level steam derrick barges are more advantageous.

The substructure should be allowed to settle at least a year before constructing the superstructure upon it. It should be carefully leveled as the superstructure is built. After the completion of the superstructure the slopes of the substructure should be examined and all holes should be filled with stones placed in position.

The width of the substructure at the water level is determined by the dimensions adopted for the superstructure, and is in this case 27 feet. Experience shows that for the purpose of estimate the interior slope may be assumed as 1 on 1.3, and the exterior slope as 1 on 2.

From the experience at the Delaware breakwaters, it is assumed that each cubic yard will require 1.34 net tons of stone. This estimate includes an allowance for settlement and misplacement.

*Superstructure.*—The inner and outer walls of the superstructure should be formed of very heavy stones laid endwise to the sea, and the space between them should be compactly filled with rubble. At the Delaware breakwaters the height of the superstructure above high water is about 9.5 feet, and the top width 20 feet. From experience at these breakwaters, however, it is considered perfectly safe to adopt for the Oswego breakwaters a height of 8 feet and a top width of 15 feet. The slope at the Delaware breakwaters is 1 on 0.7, both on the harbor and sea side of the works. This is very steep for the exterior slope, and although it has been found satisfactory at the old Delaware breakwater, a gentler slope might be found desirable where the exposure is great. A slope of 1 on 0.75 is adopted for the purposes of estimate. The width of the superstructure at the base will be 27 feet.

The walls should be laid up in three courses. Each stone should be laid with its shortest dimension vertical, and in the outer wall should weigh not less than 9,000 pounds. For the inner wall the stones may be of considerably less weight. The length of each stone should, however, be greater than its width, and it should be laid in the wall with its shortest dimension vertical and its longest dimension perpendicular to the axis of the breakwater.

Assuming 1.4 net tons per cubic yard of superstructure volume, each linear foot of superstructure will require 8.71 tons of stone for its construction.

The number of tons of stone contained in one linear foot of the breakwater is given by the formula

$$T=1.34D+0.08187D^2+8.711$$

in which D represents the depth of the water.

MATERIAL.

A good quality of limestone, weighing about 168 pounds to the cubic foot, can be obtained at Chaumont and Three-Mile Bay, N. Y. This stone is believed to have sufficient durability for breakwater construction. It can be deposited in the work at a cost not exceeding $1.20 per net ton. This price is assumed in the estimate as the average cost per ton in place for both substructure and superstructure.

LIGHTHOUSE AND FOG SIGNAL.

The harbor will require a light-house and fog signal, and their cost must be included in the estimates. They will, of course, be designed and constructed by the Light-House Board. From information kindly furnished by Lieut. Col. D. P. Heap, Corps of Engineers, engineer of the Third light-house district, it is believed that the cost of these works, including contingencies, may be estimated at about $60,000.

ESTIMATE OF COST.

The cost of constructing these works is estimated as follows:

| | |
|---|---|
| Stone in place, 941,931 net tons, at $1.20 | $1,130,317.20 |
| Contingencies | 114,682.80 |
| Total for breakwaters | 1,245,000.00 |
| Light-house and fog signal | 60,000.00 |
| Total | 1,305,000.00 |

The profiles of the breakwaters and the details of the estimate are shown on figures 1 to 6, inclusive.

OLCOTT.

The existing harbor at this locality is situated at the mouth of Eighteen-Mile Creek, which is about 18 miles east of the mouth of the Niagara River. The exposure is much less than at Oswego. The movement of wave-worn material is from west to east. The bottom consists of sandstone overlaid by sand and gravel.

The entrance to the harbor is formed by two parallel crib breakwaters extending outward from the shore for distances of 850 and 873 feet, the width between them being about 200 feet. These works were constructed between the years 1867 and 1882. The harbor is excavated in the bed of the creek inside the shore line of the lake. The locations of the piers and harbors are shown on plate 17.

The canal designed by the Board enters the lake a short distance

east of the existing piers. The channel connecting it with deep water in the lake will be about 3,680 feet long and 600 feet wide, and has a direction a little west of north. Piers for mooring and guiding vessels at the entrance are not provided, as there will be ample anchorage area and mooring facilities in the basin of the canal within the shore line. A crib pier on each side of the entrance to clearly mark its location is all that is considered necessary. The first lock is about 5,000 feet above the entrance.

### PLAN OF THE BREAKWATERS.

The breakwaters are required to shelter the entrance to the canal from heavy seas and to protect the excavated channel from shoaling. As before remarked, it is not necessary to provide for anchorage areas outside the shore line.

The breakwaters are designed to start from the shore at a distance of 300 feet from the channel, making the interval between them 1,200 feet. They are carried out parallel to each other for a distance of 1,840 feet from the shore, or half the distance from the lake entrance. From this point they converge on arcs of circles out to a depth of 35 feet, so as to give the entrance a clear width of 600 feet. This plan has the advantage of forming a stilling basin to moderately reduce the height of waves during storms.

The aggregate length of the proposed breakwaters is 5,395 feet. Their locations are shown on figs. 7 to 12, inclusive.

### CHARACTER, CONSTRUCTION, AND CROSS SECTION OF THE BREAKWATERS.

For the reasons fully stated in connection with the investigation of the breakwaters designed for Oswego it is proposed to construct these breakwaters of random stone, in accordance with the general method adopted for the breakwaters in Delaware Bay. The cross section and details of construction and the data employed will be the same as heretofore described for the works at Oswego, with the exception of the price of stone, which is taken at $1.35 instead of $1.20 per net ton, the works in this case being much farther from the quarries.

### ESTIMATE OF COST.

The cost of constructing the works is estimated as follows:

| | |
|---|---|
| Stone in place, 388,670 net tons, at $1.35 | $524,704.50 |
| Contingencies | 55,295.50 |
| Total for breakwaters | 580,000.00 |
| Light-house and fog signal | 60,000.00 |
| Total | 640,000.00 |

The profiles of the breakwaters and the details of the estimate are shown on figs. 7 to 12, inclusive.

BREAKWATERS FOR A WATERWAY HAVING A DEPTH OF 21 FEET.

The same general plans are adopted; but the lengths of the breakwaters, and consequently the cost of construction, may be considerably reduced.

OSWEGO.

The locations of the breakwaters proposed for the 21-foot waterway are shown on fig. 4, and the profiles and details of the estimate on figs. 5 and 6.

ESTIMATE OF COST.

| | |
|---|---|
| Stone in place, 551,150 net tons, at $1.20 | $661,380.00 |
| Contingencies | 66,120.00 |
| Total for breakwaters | 727,500.00 |
| Light-house and fog signal | 60,000.00 |
| Total | 787,500.00 |

OLCOTT.

The locations of the breakwaters proposed for the 21-foot waterway are shown on fig. 10, and the profiles and details of the estimate on figs. 11 and 12.

ESTIMATE OF COST.

| | |
|---|---|
| Stone in place, 175,062 net tons, at $1.35 | $236,333.70 |
| Contingencies | 23,666.30 |
| Total for breakwaters | 260,000.00 |
| Light-house and fog signal | 60,000.00 |
| Total | 320,000.00 |

Respectfully submitted.

C. W. RAYMOND,
*Lieutenant-Colonel, Corps of Engineers.*

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

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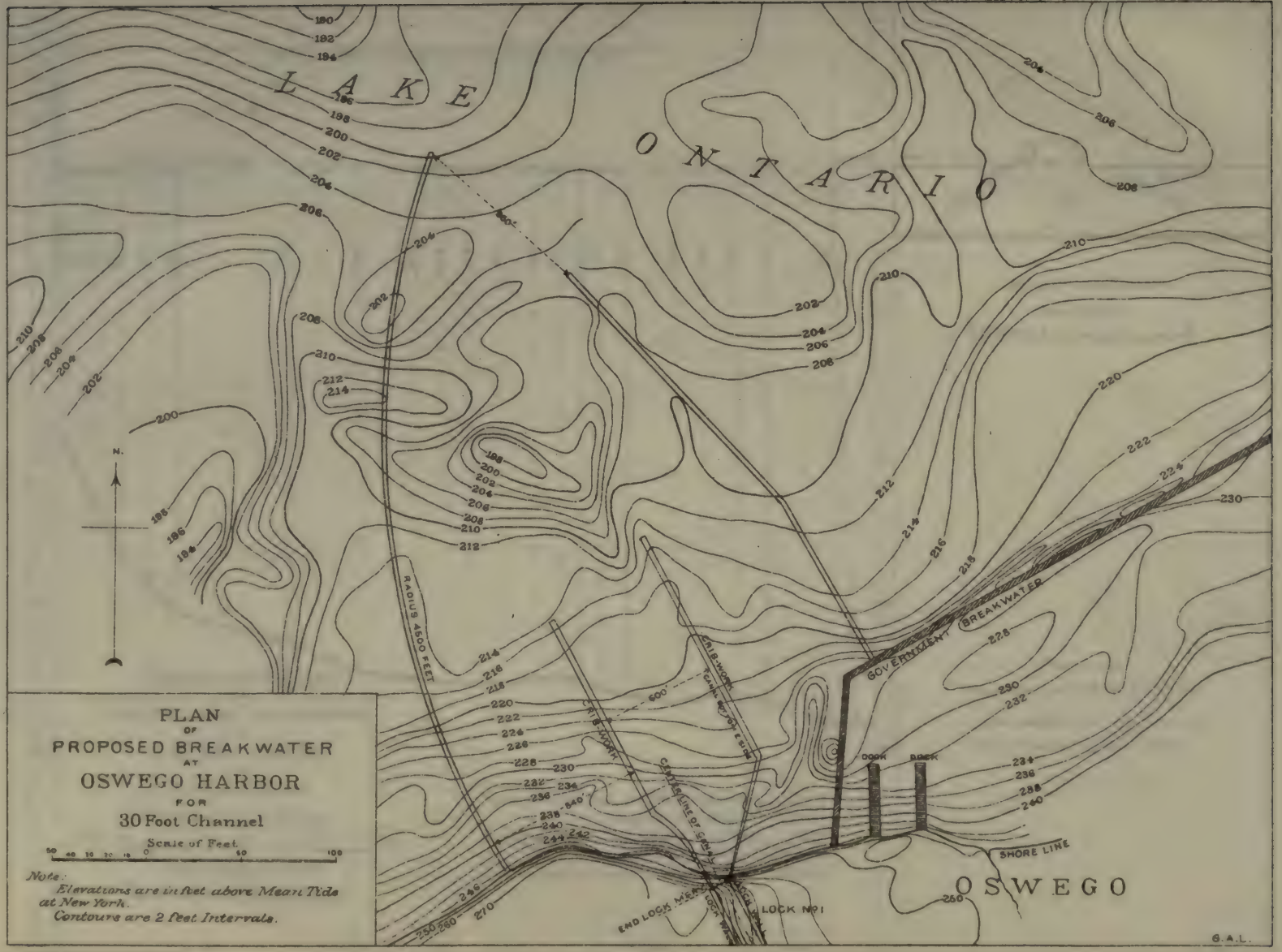
## APPENDIX NO. 4.

### SPEED OF SHIPS.

SPEED OF SHIPS IN THE PROPOSED DEEP WATERWAY.

The speed which ships can attain in the different sections of the proposed deep waterway is a question vital to a discussion of the facilities it would offer for economical transportation. For this purpose there is needed a definite schedule of speeds which a ship is likely to attain in each of its several sections. Previous discussions of the

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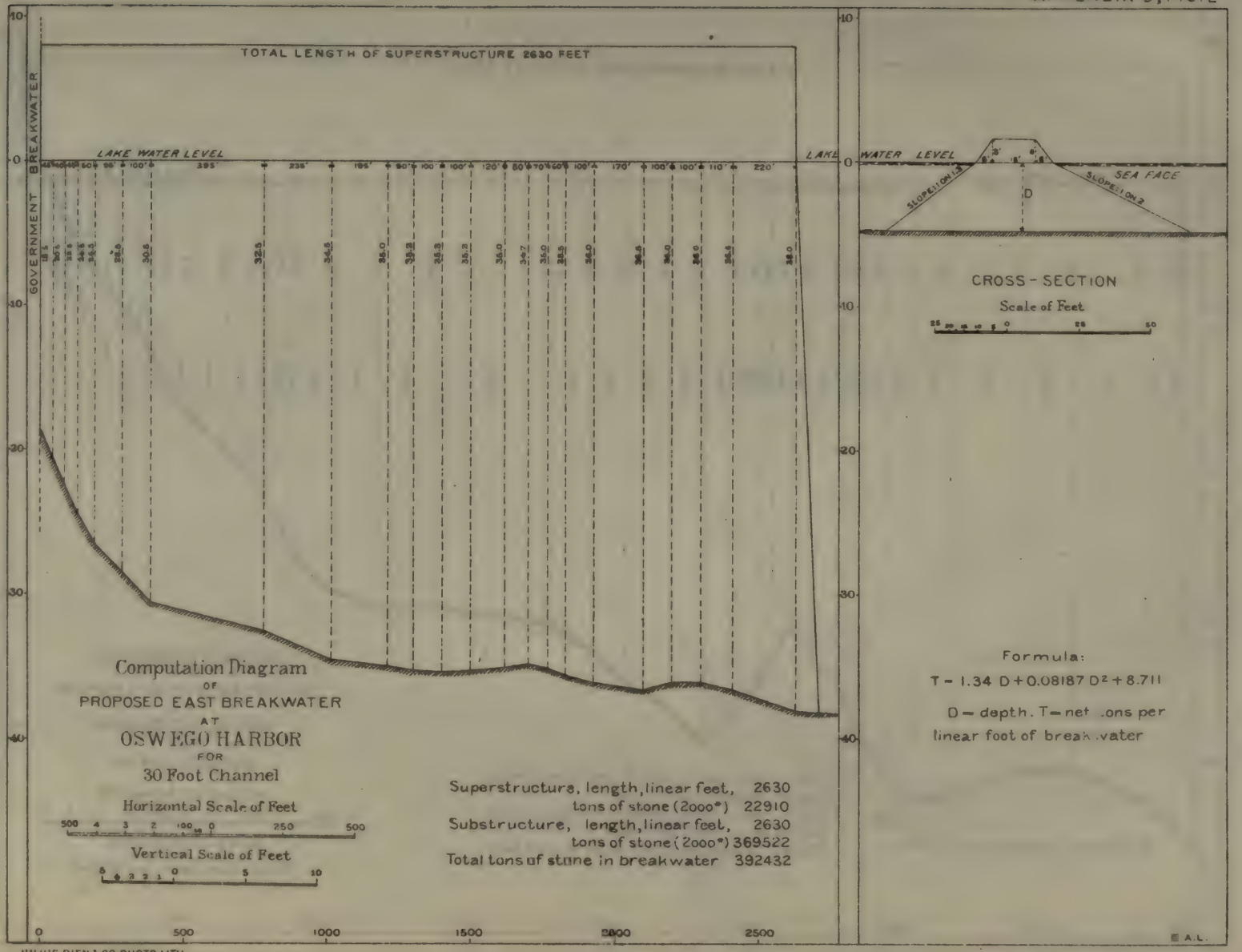


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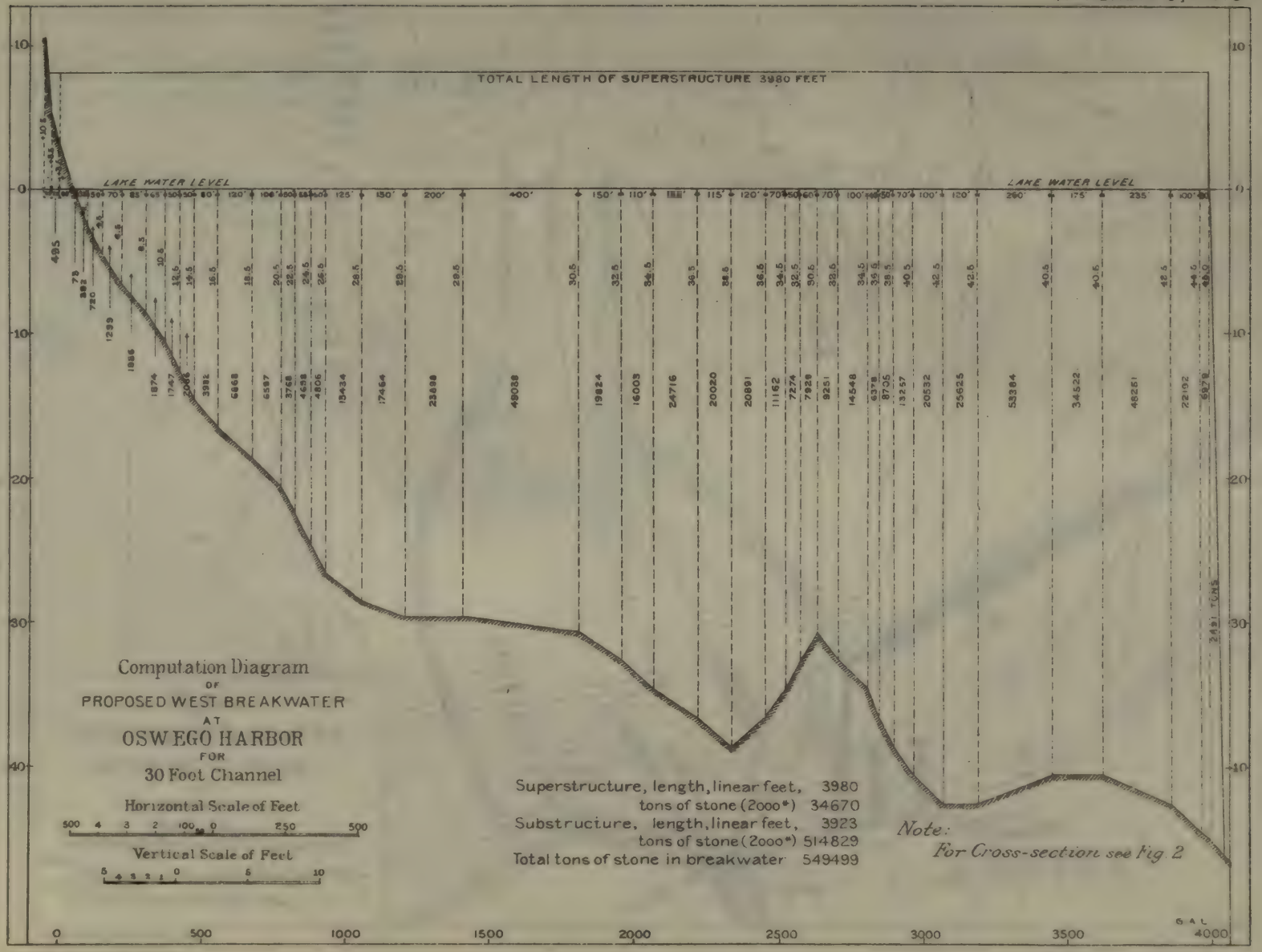
TOTAL LENGTH OF SUPERSTRUCTURE 3980 FEET
LAKE WATER LEVEL
LAKE WATER LEVEL
Computation Diagram
OF
PROPOSED WEST BREAKWATER
AT
OSWEGO HARBOR
FOR
30 Foot Channel
Horizontal Scale of Feet
500 4 3 2 100 0 250 500
Vertical Scale of Feet
5 4 3 2 1 0 5 10
Superstructure, length, linear feet, 3980
tons of stone (2000*) 34670
Substructure, length, linear feet, 3923
tons of stone (2000*) 514829
Total tons of stone in breakwater 549499
Note:
For Cross-section see Fig. 2
0 500 1000 1500 2000 2500 3000 3500 4000
SAL

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LAKE ONTARIO
RADIUS 5300 FEET
RADIUS 3000 FEET
RADIUS 4700 FEET
RADIUS 1800 FEET
LENGTH 1820 FEET
RADIUS 3500 FEET
LENGTH 1700 FEET
GOVERNMENT BREAKWATER
CRIBWORK
CENTRE LINE OF CANAL
SHORE LINE
OSWEGO
END LOCK ABUTMENT
BLOCK No 1
PLAN
OF
PROPOSED BREAKWATER
AT
OSWEGO HARBOR
FOR
21 Foot Channel
Scale of Feet
Note:
Elevations are in feet above Mean Tide at New York
Contours are 2 feet Intervals.
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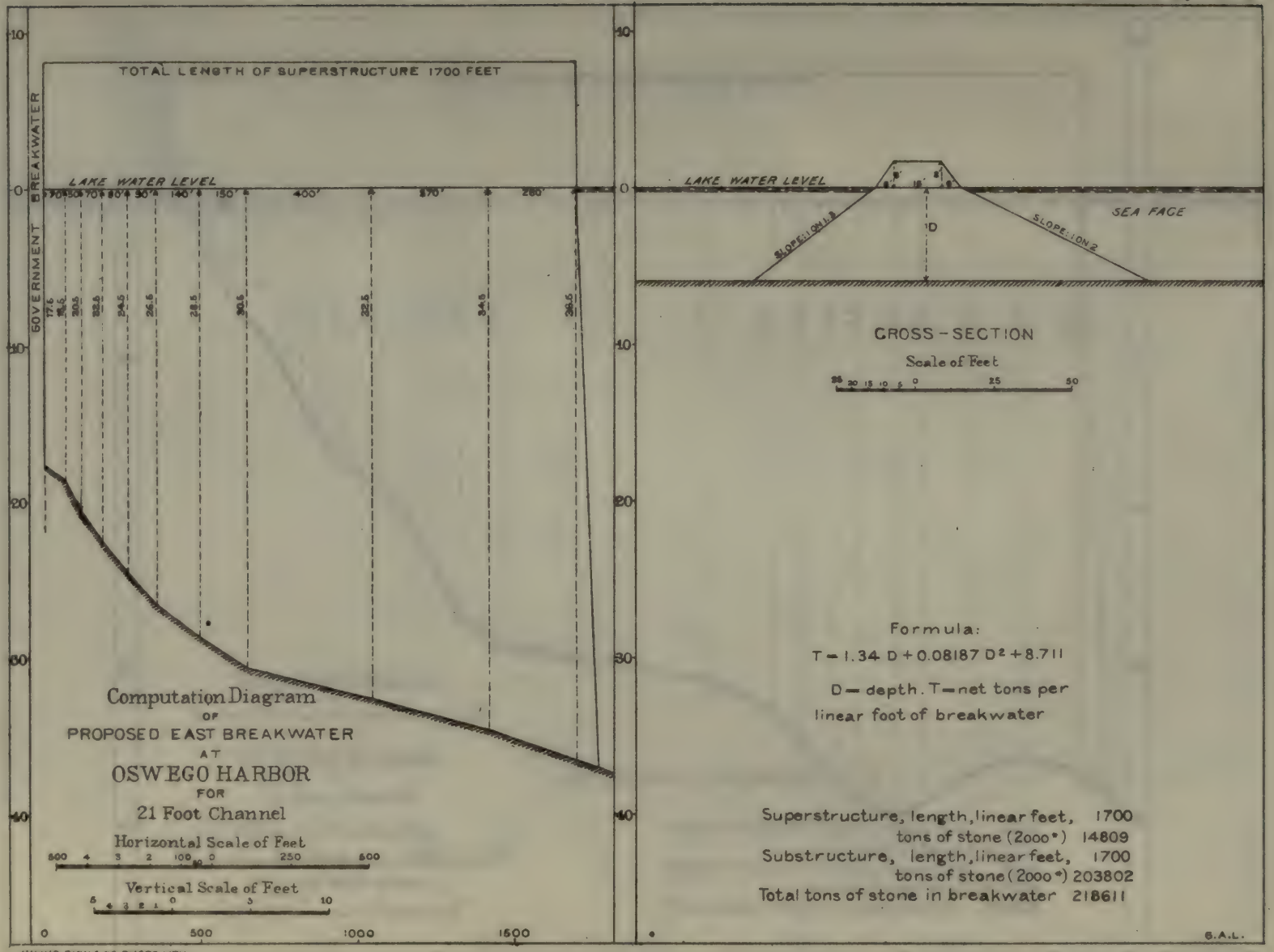
TOTAL LENGTH OF SUPERSTRUCTURE 1700 FEET
GOVERNMENT BREAKWATER
LAKE WATER LEVEL
70' 50' 70' 80' 90' 140' 150' 400' 370' 280'
17.5 19.5 20.5 22.5 24.5 26.5 28.5 30.5 32.5 34.5 36.5
Computation Diagram
OF
PROPOSED EAST BREAKWATER
AT
OSWEGO HARBOR
FOR
21 Foot Channel
Horizontal Scale of Feet
Vertical Scale of Feet
0 500 1000 1500
LAKE WATER LEVEL
SLOPE 1 ON 1.8
D
SLOPE 1 ON 2
SEA FACE
CROSS-SECTION
Scale of Feet
Formula:
T = 1.34 D + 0.08187 D² + 8.711
D = depth. T = net tons per linear foot of breakwater
Superstructure, length, linear feet, 1700
tons of stone (2000#) 14809
Substructure, length, linear feet, 1700
tons of stone (2000#) 203802
Total tons of stone in breakwater 218611
G.A.L.

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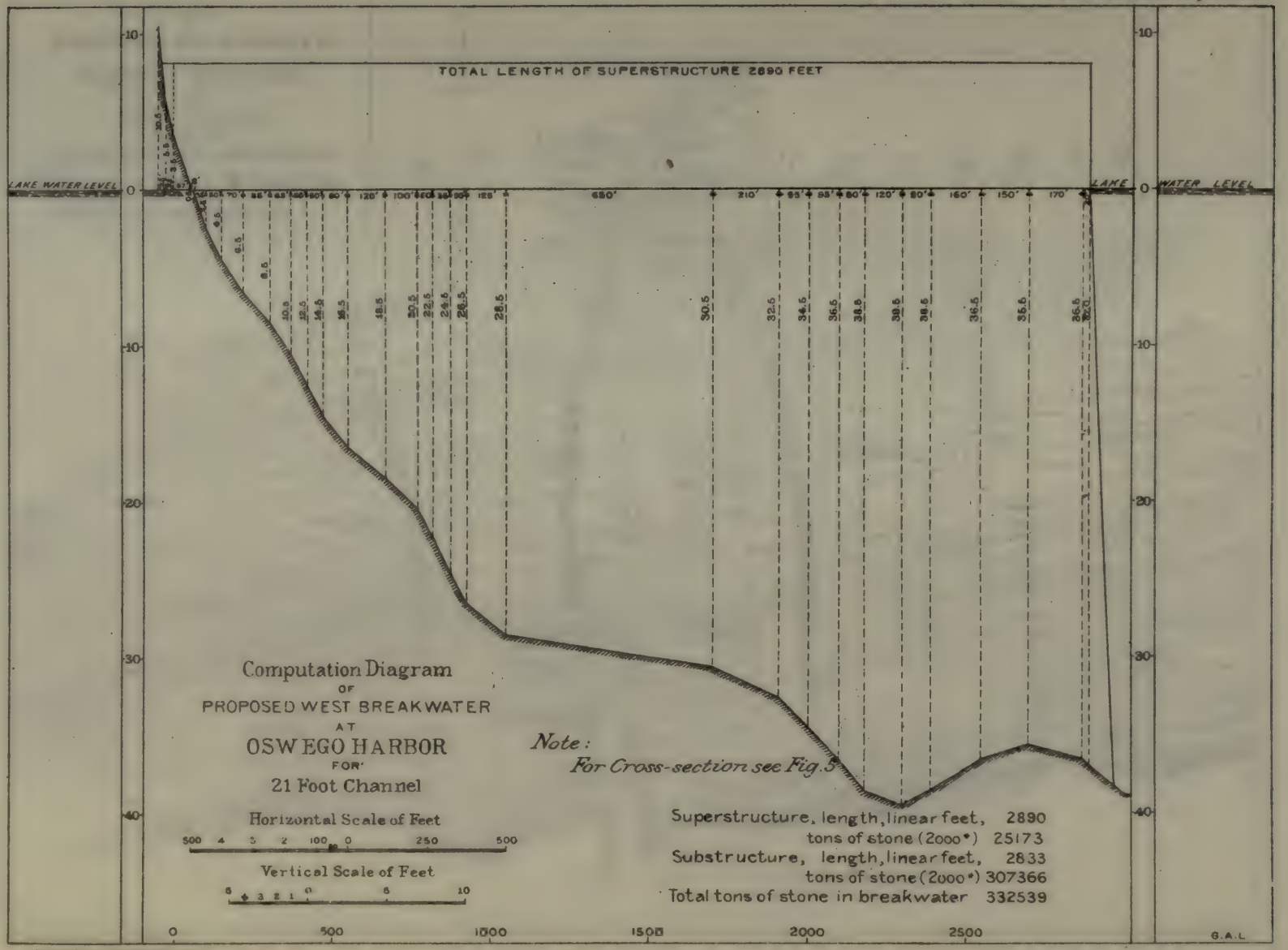


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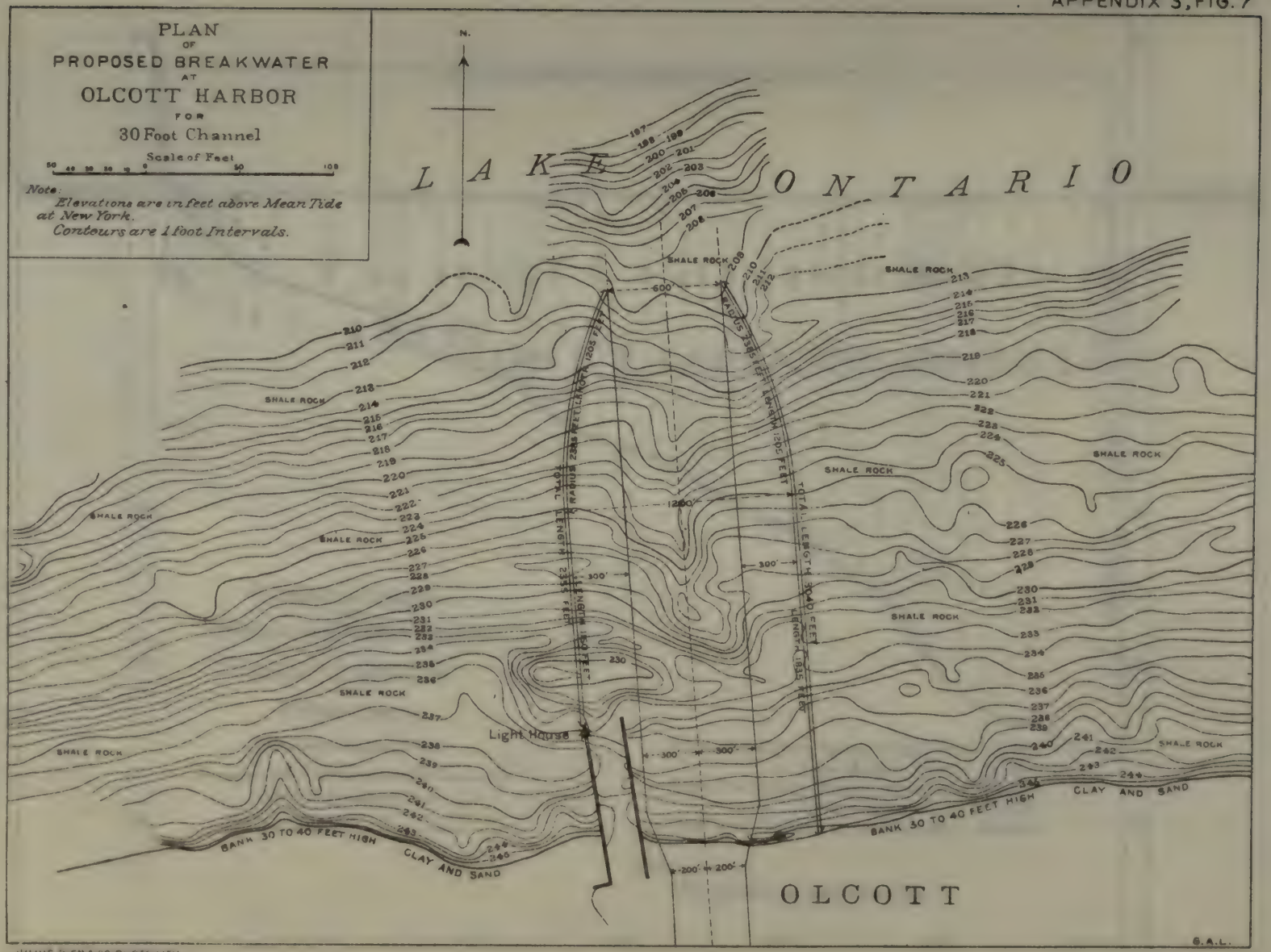
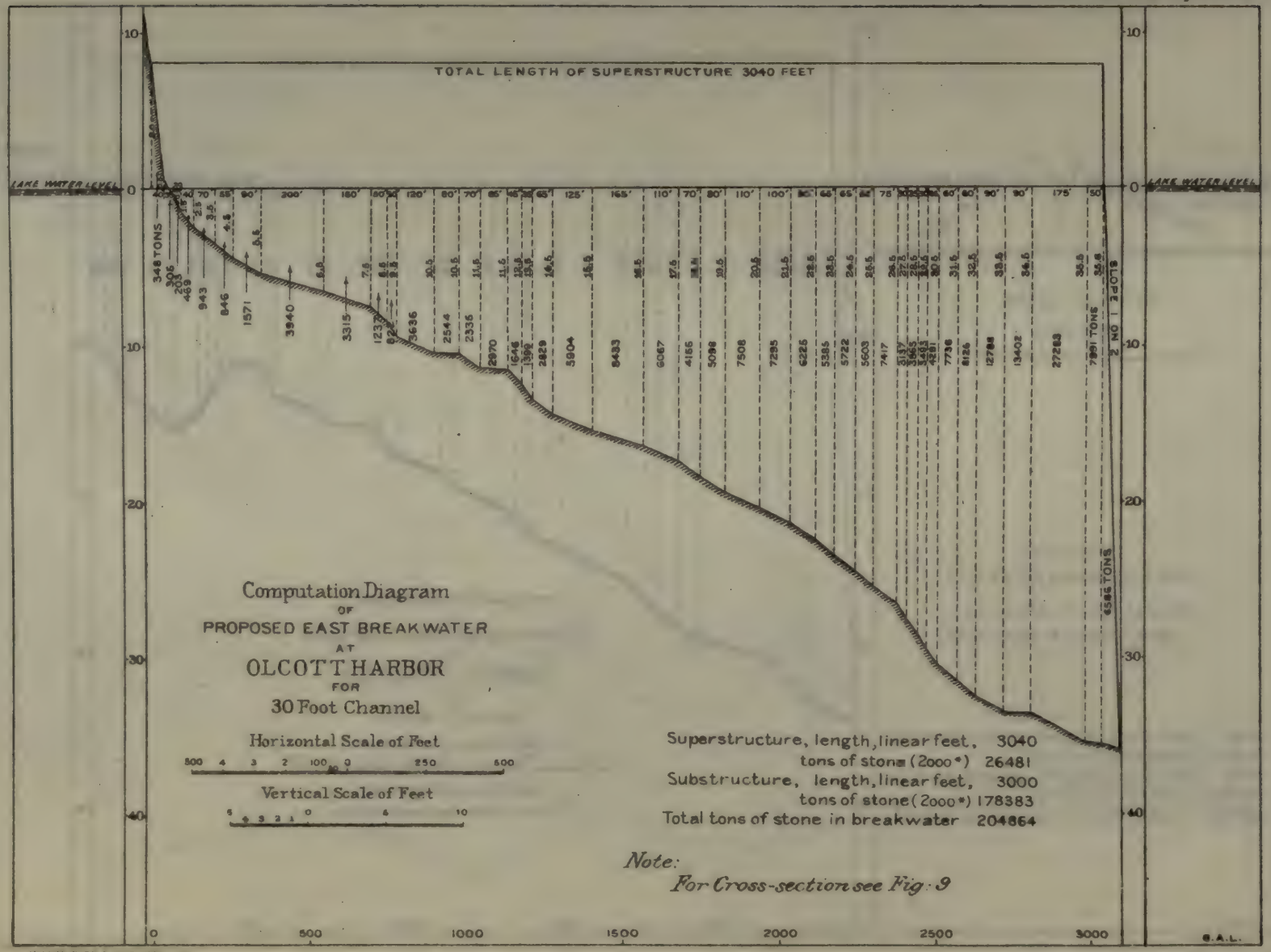

PLAN
OF
PROPOSED BREAKWATER
AT
OLCOTT HARBOR
FOR
30 Foot Channel
Scale of Feet
50 40 30 20 10 0 50 100
Note.
Elevations are in feet above Mean Tide at New York.
Contours are 1 foot Intervals.
N.
LAKE ONTARIO
SHALE ROCK
BANK 30 TO 40 FEET HIGH
CLAY AND SAND
Light House
OLCOTT
600'
1200'
300'
200'
JULIUS BIEN & CO. PHOTO LITH.
G.A.L.

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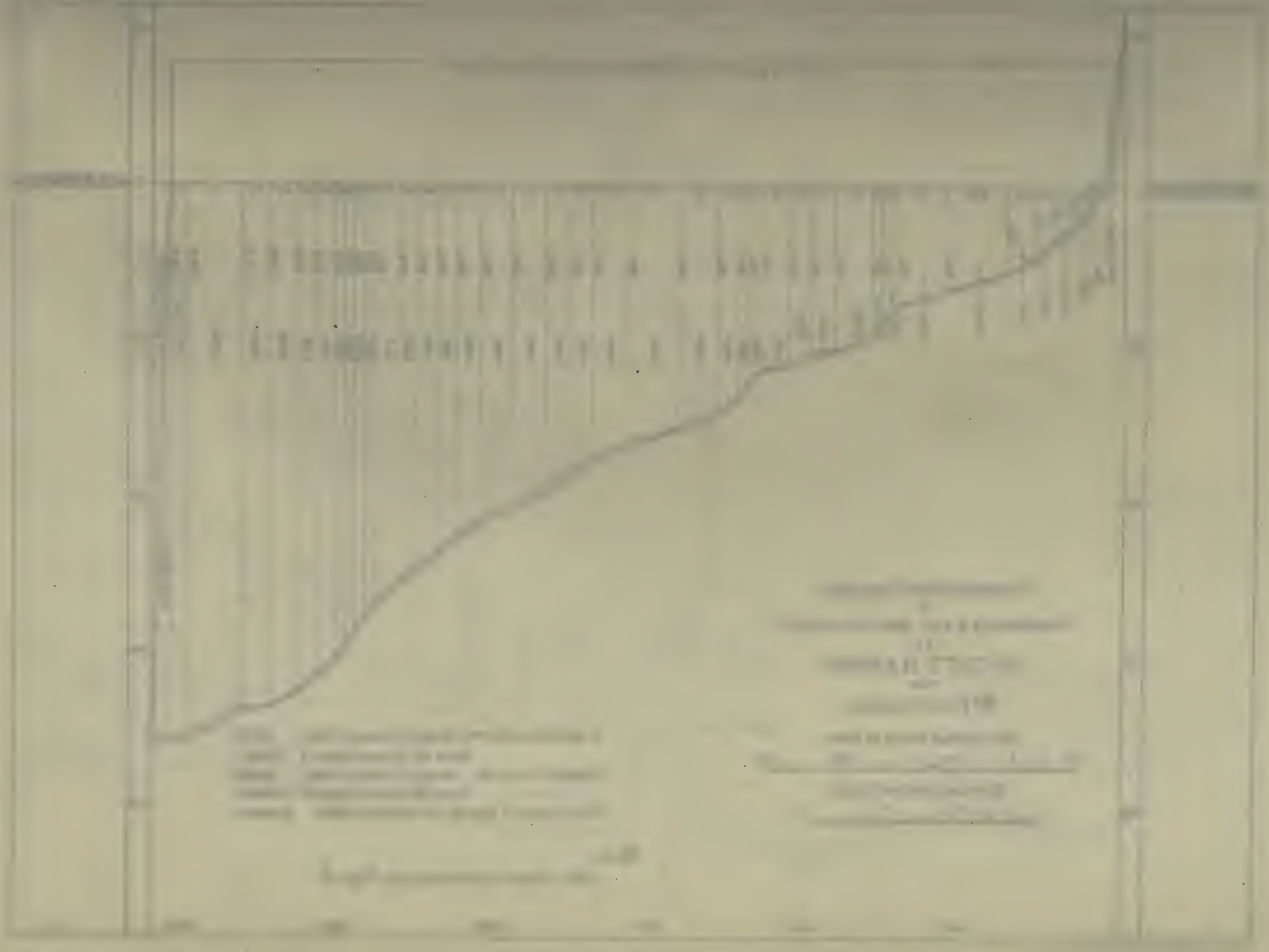

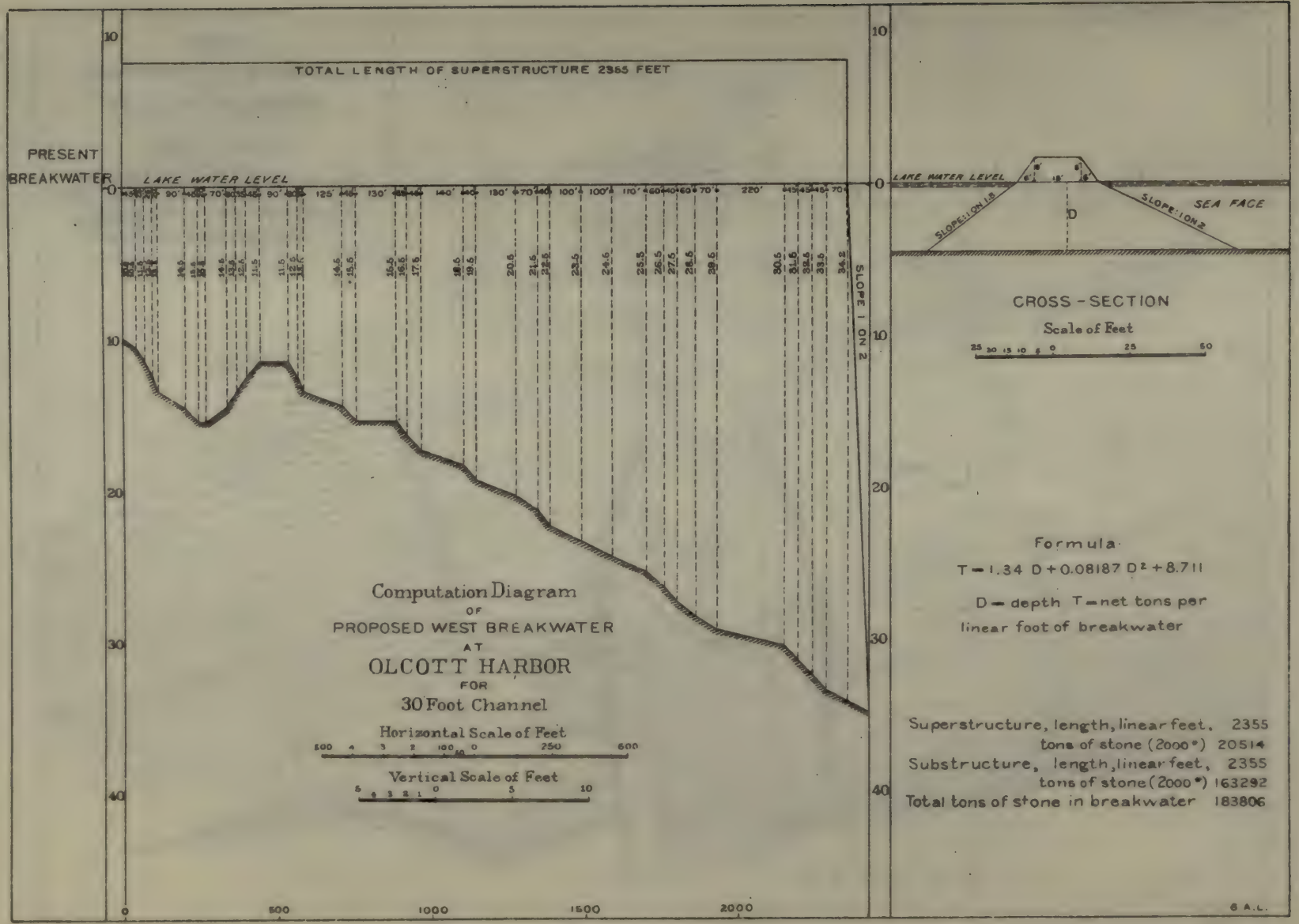


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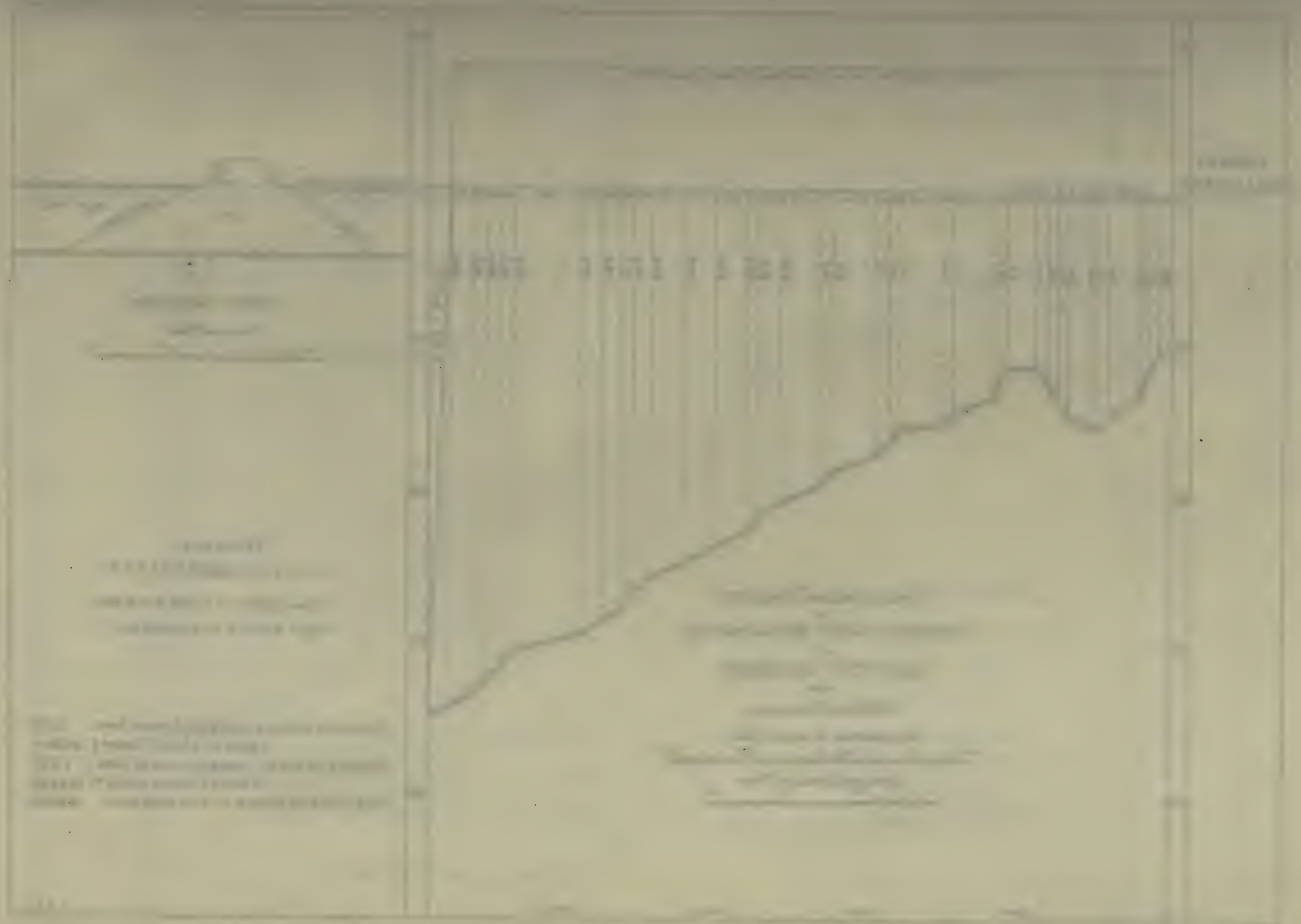

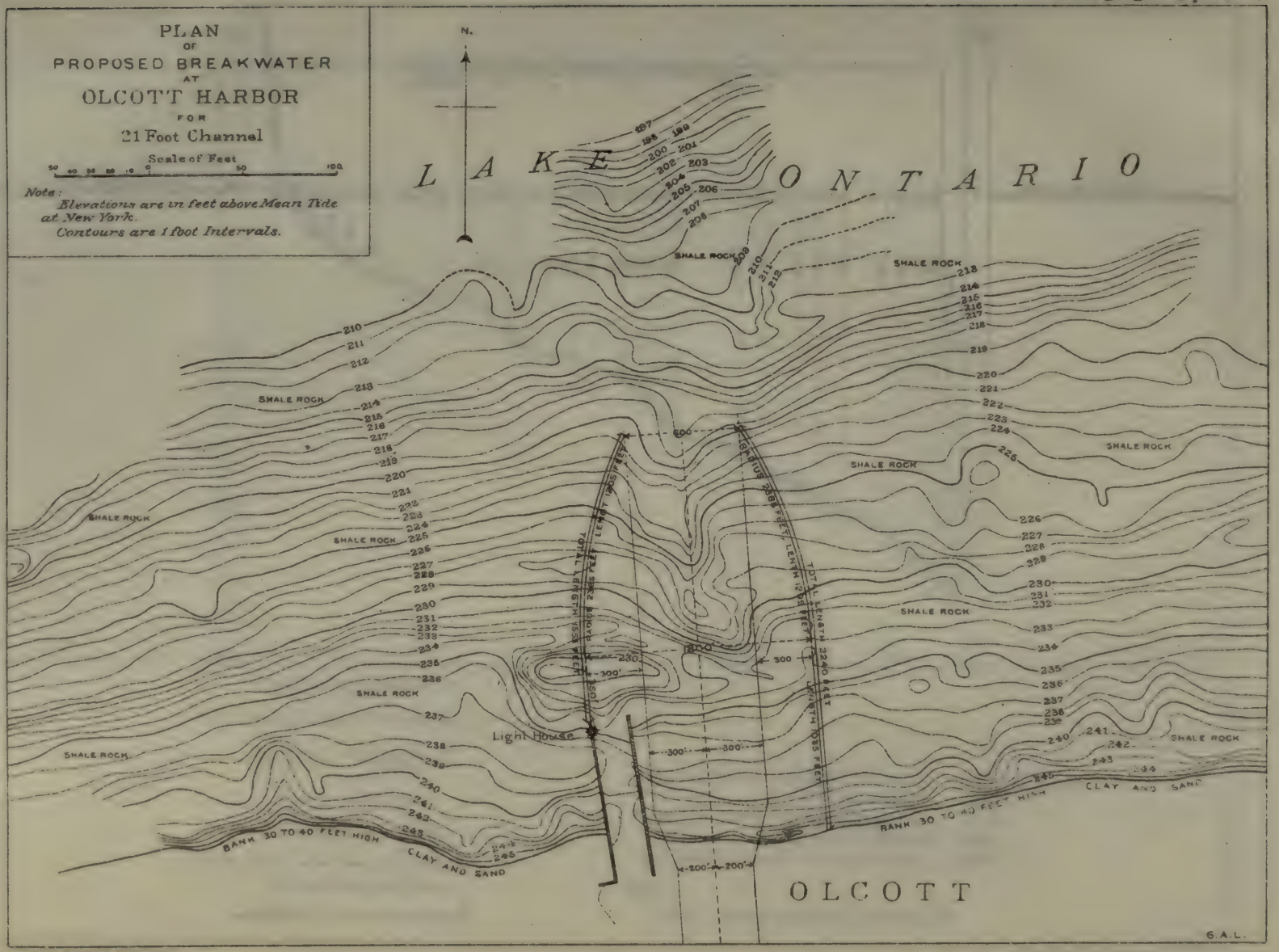


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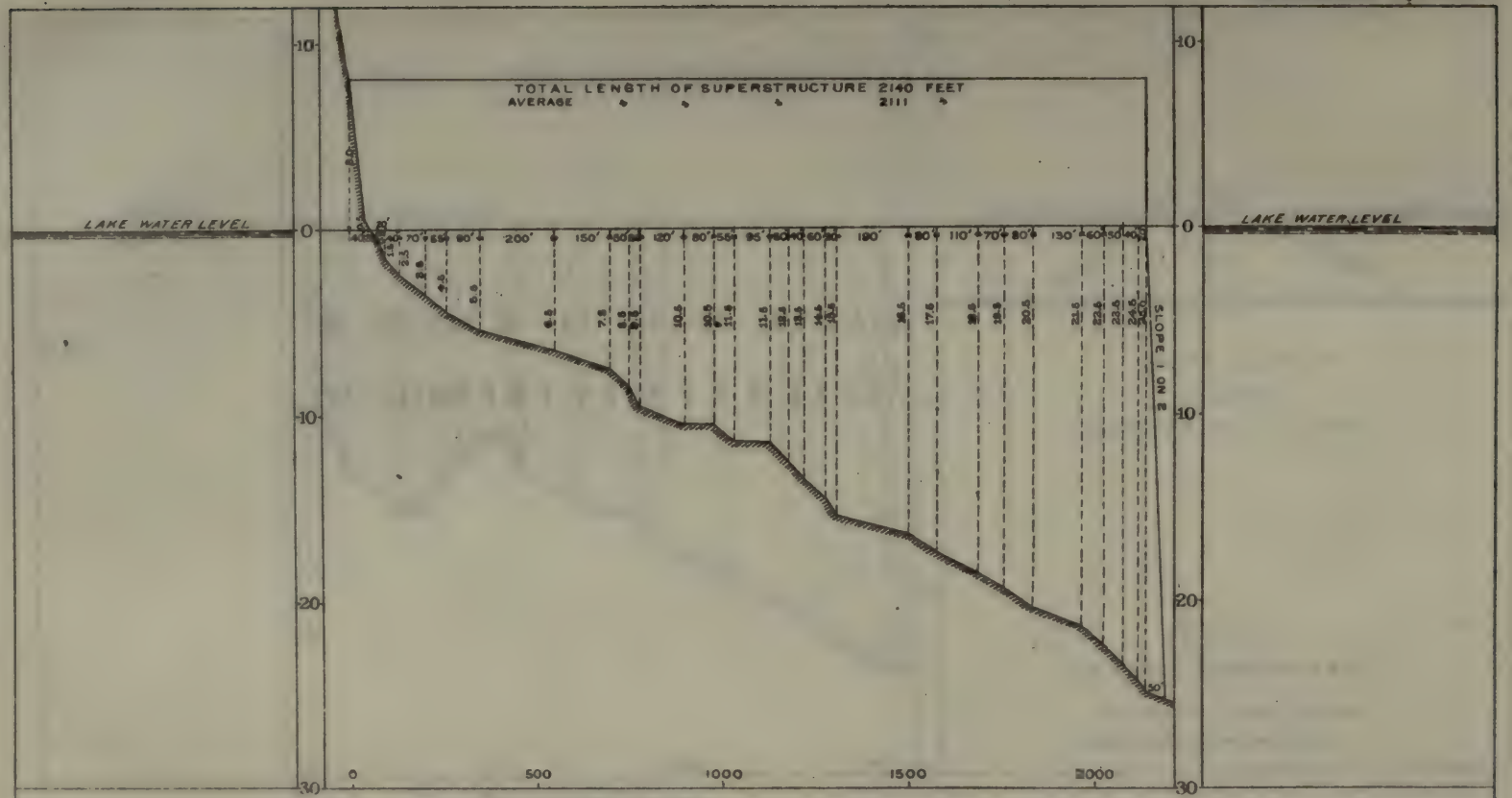


## Computation Diagram
OF
PROPOSED EAST BREAKWATER
AT
OLCOTT HARBOR
FOR
21 Foot Channel

Horizontal Scale of Feet

Vertical Scale of Feet

| | | |
|---|---|---|
| Superstructure, length, linear feet, | 2111 | (Average) |
| tons of stone (2000 #) | 18389 | |
| Substructure, length, linear feet, | 2108 | |
| tons of stone (2000 #) | 70744 | |
| Total tons of stone in breakwater | 89133 | |

*Note:*
*For Cross-section see Fig. 12*

G.A.L.

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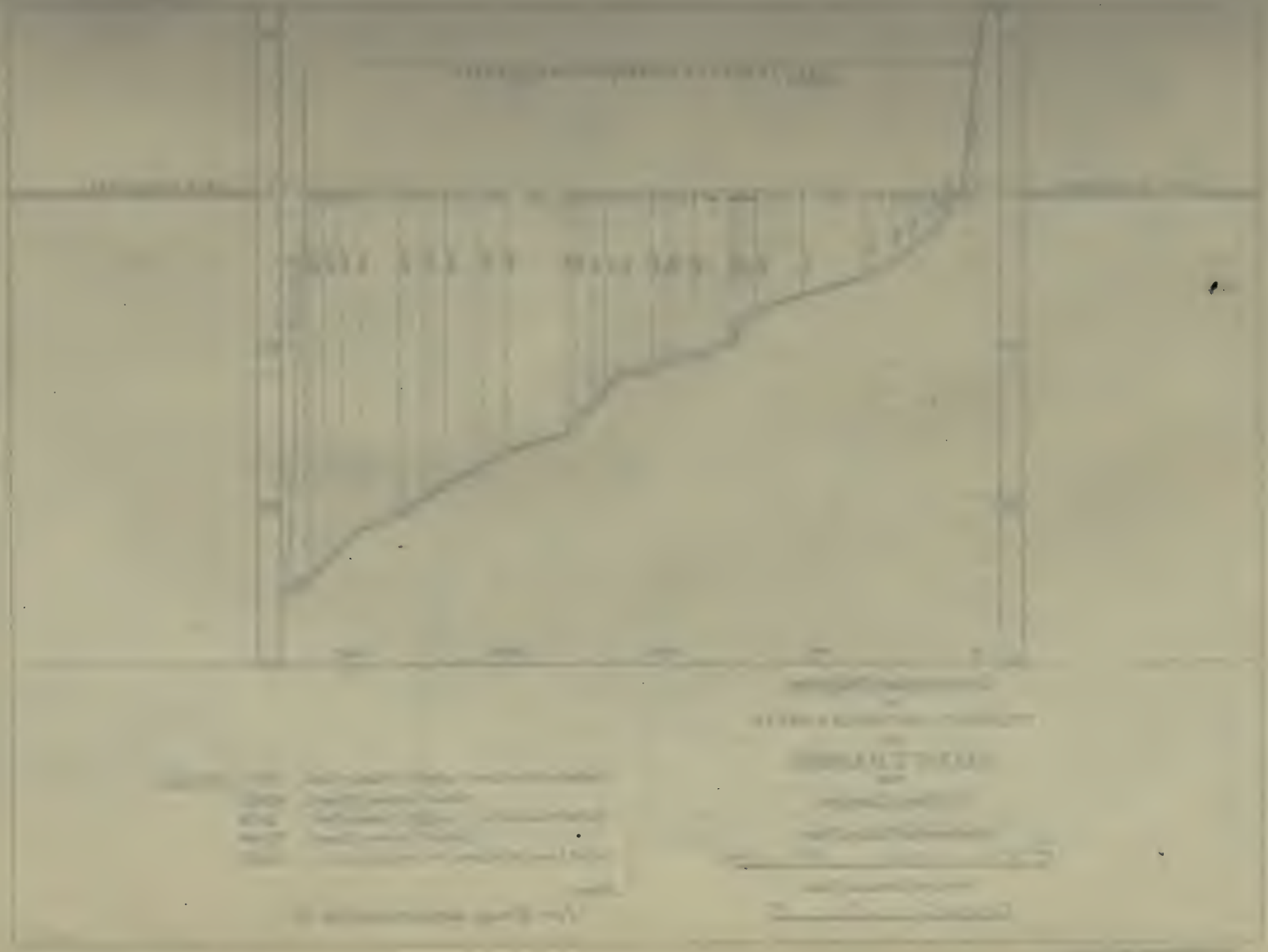

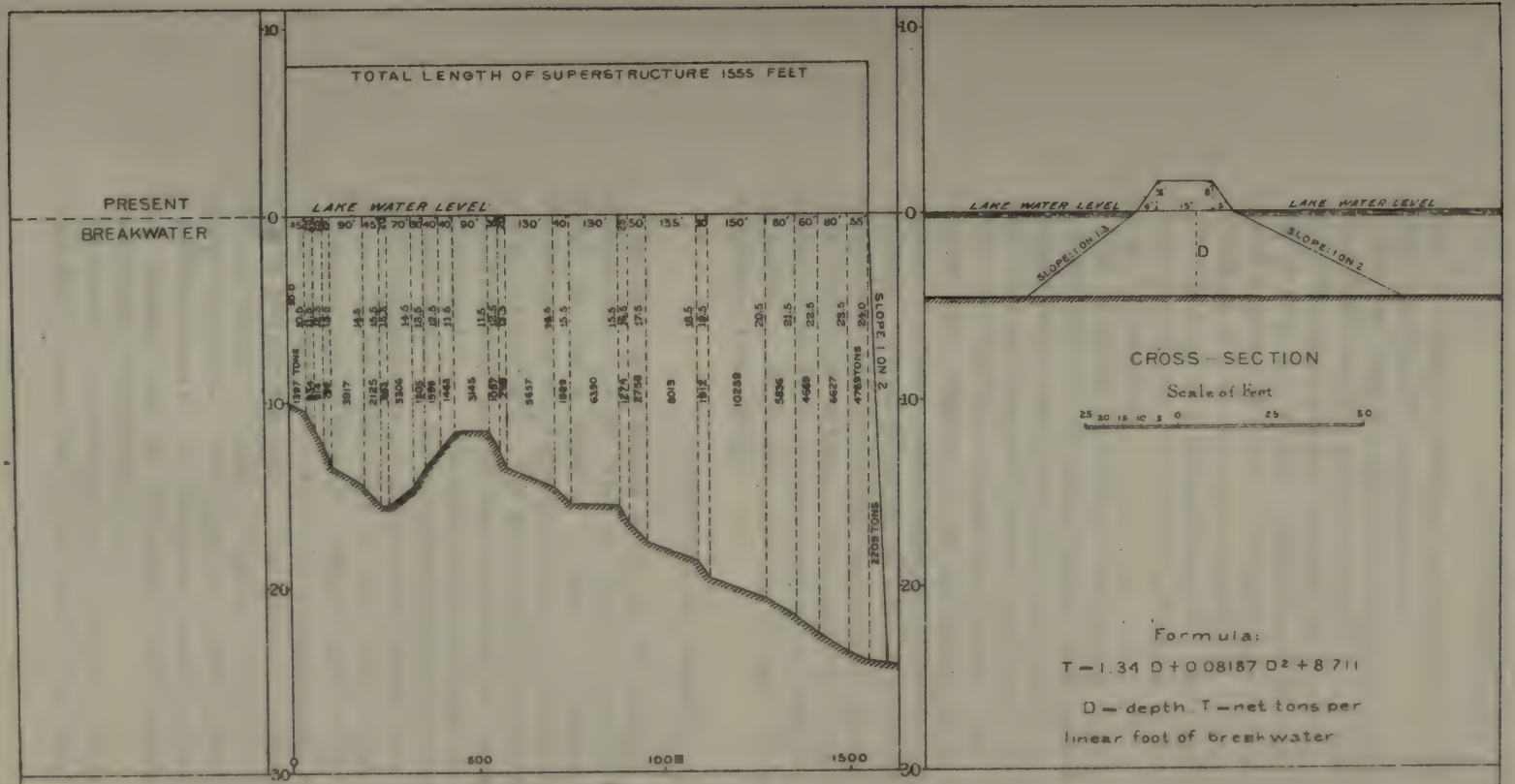


Formula:

$T = 1.34\,D + 0.08187\,D^2 + 8.711$

D = depth. T = net tons per linear foot of breakwater

## Computation Diagram
OF
PROPOSED WEST BREAKWATER
AT
## OLCOTT HARBOR
FOR
21 Foot Channel

Horizontal Scale of Feet

Vertical Scale of Feet

| | |
|---|---|
| Superstructure, length, linear feet, | 1555 |
| tons of stone (2000#) | 13546 |
| Substructure, length, linear feet, | 1580 |
| tons of stone (2000#) | 72383 |
| Total tons of stone in breakwater | 85929 |

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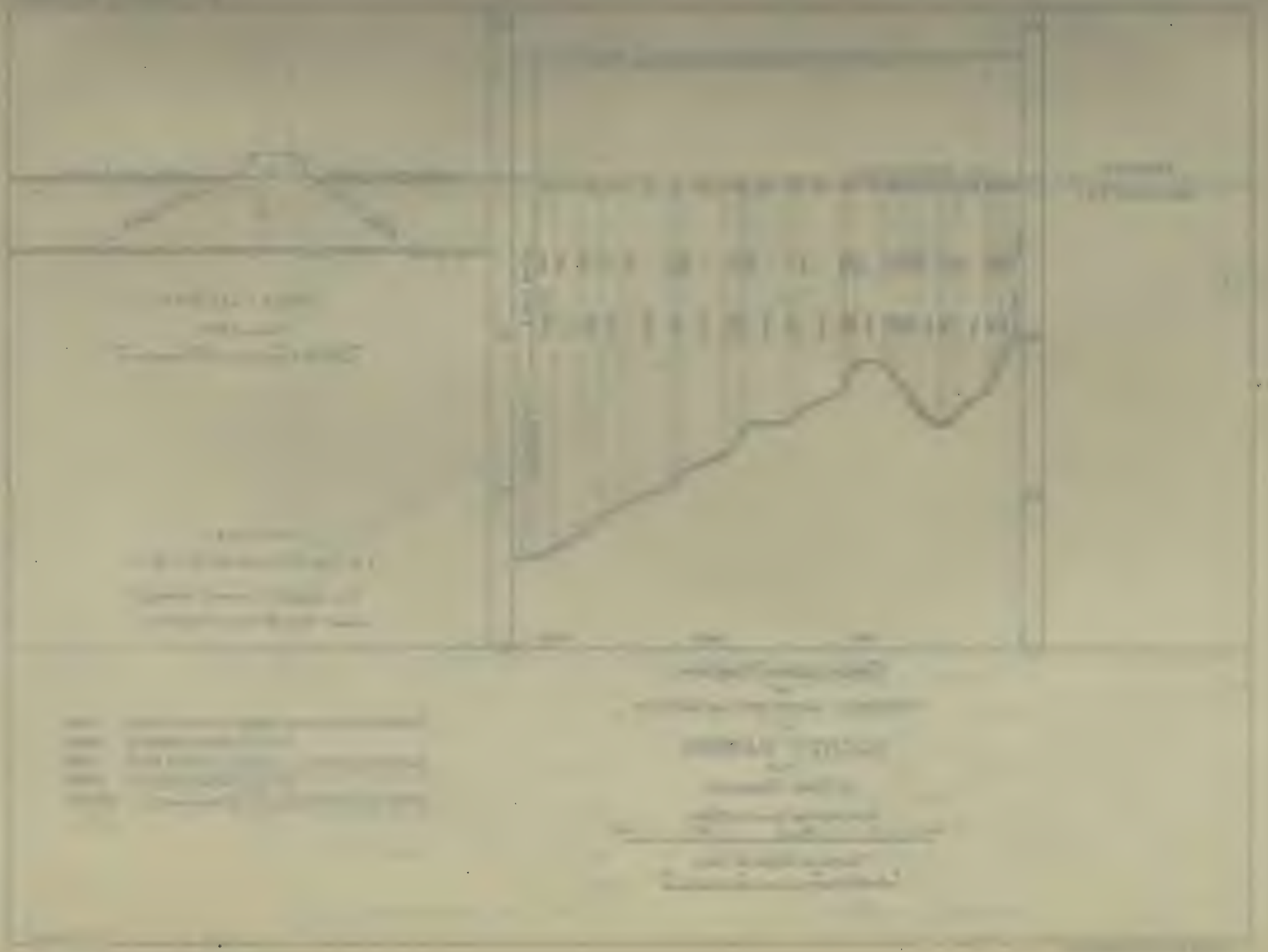


speed of ships in restricted channels have had reference mostly to small canal boats in narrow canals.

Recorded observations on the movement of large ships in restricted waterways are not wholly lacking, but they relate in general to channels differing so greatly in dimensions from the proposed deep waterway as to have a limited application in the establishment of the proposed schedule of speeds. To state the situation more definitely, if it be desired to draw a curve which shall express the relation between the cross section of the waterway and the attainable safe speed of a given ship therein, recorded observations serve only to fix one or two points in the curve.

This being the situation, it was thought that a study of the causes of retardation of a ship when passing from open water into a restricted channel might possibly be useful. If all these causes could be stated and evaluated, the result would be a correct schedule of speeds with which recorded observations would agree. No such result, however, is attainable, because it is impracticable either to make a complete statement of the causes of retardation or to evaluate any of them with precision. The scope of the investigation was therefore limited to an examination of the principal causes of retardation and to an approximate evaluation of them. The speed curve resulting from an investigation of this kind will have little value unless checked at some point or points by observation, and its ultimate value depends upon the number of such checks.

## DIMENSIONS OF WATERWAY.

The study takes up the two types of waterway on which the Board is required to report. One of them is to have a depth of 30 feet of water, the other a depth of 21 feet. The standard cross sections of these channels when formed in earth are shown on figs. 2 and 3 of the report of the Board. The bottom widths shown are minima. In certain localities greater widths are required by conditions which will not be discussed here. The practicable speed depends so much on the area of cross section of the waterway that this discussion embraces necessarily a large range above the given minima and includes the entire range of widths laid down for the proposed deep waterway. It is confined to speeds through cross sections in earth. A small portion of the deep waterway is in rock with a slightly smaller cross section than in the earth section. The sides of the rock sections are to be vertical, which will make navigation safer than through an earth section of equal area. The aggregate length of channel in rock section is relatively small. It is believed, therefore, that the introduction of rock channels into the discussion would complicate and extend it considerably without useful result.

The area of the minimum or "standard" cross section in earth is about 8,000 square feet for the 30-foot channel, corresponding to a

bottom width of 203⅛ feet. For convenience, the bottom width is taken at 203 feet, making the exact area of the standard cross section for the 30-foot channel 7,990 square feet. The area of the minimum or "standard" cross section for the 21-foot channel is about 5,500 square feet, corresponding to a bottom width of 215¼ feet. For convenience, the bottom width is taken at 215 feet, making the exact area of the "standard" cross section for the 21-foot channel 5,497 square feet.

### TYPE OF SHIPS.

The characteristics of the type ship which must be considered here are its dimensions, speed, and probable character of its business, whether freight exclusively or combined passenger and freight. A large and increasing proportion of freight across the North Atlantic is carried in ships with limited passenger accommodations and running at speeds of 16 to 18 statute miles per hour. A route including with the crossing of the Atlantic a farther distance inland of 1,300 to 1,400 miles would probably attract few passengers for the inland portion and accommodations for passengers would be less profitable. Furthermore, only a small portion of the freight carried from the lakes to tide water will be destined for export, but will be marketed and consumed in the Eastern States. Passenger accommodations would therefore be made use of only a small part of the time. It is believed, therefore, that by far the greater part of the commerce through the deep waterway will be carried in exclusively freight ships.

As to the economical speed of freight ships, the greater part of freight transported by sea is carried by ships running 10 to 13 statute miles per hour. The most recent freight ships built on the lakes have speeds of 12 to 12½ miles per hour. Although these facts point to a speed not exceeding 13 miles per hour as the economical one, they are not absolutely conclusive, and it seemed necessary to study the effect on cost of transportation of increased speed. To this end estimates were procured from the well-known naval architect and shipbuilder, Mr. Frank E. Kirby, of the cost of building and operating ships of different dimensions at each of two rates of speed, viz, 12½ and 15 statute miles per hour. These estimates are given and discussed in No. 5. The conclusion is clearly shown that the increase of speed would add largely to the cost of transportation. The rate of 12½ statute miles per hour is therefore adopted in this discussion.

It is obvious that the economical dimensions of ships must vary with their draft. For this reason the 30 and 21 foot channels must be considered separately.

Mr. Kirby's estimates cover a range of dimensions from 480 feet long over all by 52 feet beam, to 550 feet long by 60 feet beam, all of 27-foot draft. The lowest transportation cost figure while the ship is en route from the head of the lakes to the seaboard is given by a ship 500 feet

long by 54 feet beam. When the delay at terminals is taken into account the result is not changed. However, the cost of transportation increases slowly with increase of ship dimensions, and further improvements in shipbuilding are likely to lead to greater dimensions. For this reason it appears judicious to take for the 30-foot waterway in this discussion a ship somewhat larger than appears economical under present conditions. The dimensions taken are a length of 540 feet over all and a beam of 58 feet, the draft, fully loaded, being taken at 27 feet.

For the 21-foot channel it seems best to adhere closely to the dimensions of the largest ships yet built. As the full-load draft of these ships is limited to about 20 feet, the difficulty of giving them sufficient strength increases rapidly with their length, and the limit in length on the present draft is generally believed to have been reached; the beam may admit of further development. The type ship chosen for this discussion is of the largest class—not quite so long as the longest, but of the greatest beam yet adopted. The dimensions are 480 feet long over all, 52 feet beam, and 19 feet draft.

The dimensions of the type ships and other particulars relating to them, taken from Mr. Kirby's estimates, are given in the following table:

TABLE I.—*Type ships.*

| | Ship for 30-foot waterway. | Ship for 21-foot waterway. |
|---|---|---|
| Length over all | 540 | 480 |
| Beam | 58 | 52 |
| Draft | 27 | 19 |
| Coefficient of fineness | 80 | 80 |
| Displacement.....net tons | 20,300 | 11,700 |
| Cargo capacity.....do | 13,980 | 8,600 |
| Horsepower of engines | 3,200 | 2,200 |
| Single or twin screws | Twin. | Single. |

## PRINCIPAL CAUSES OF REDUCTION OF SPEED OF SHIPS IN RESTRICTED WATERWAYS.

1. The speed attained by a ship in open sea will be reduced in a marked degree on entering shoal water, even if of unlimited width.

2. If the channel is restricted laterally as well as in depth, the water moves back past the ship in the effort to maintain a uniform level in the channel. The speed of the ship past a fixed point becomes less than its speed in relation to the water through which it moves.

3. The piling up of water in front of the ship and the lowering of water behind it set up a resistance to its motion. This takes place to some extent in open sea. This discussion is concerned only with changes of condition when passing from open sea into a restricted channel.

4. The speed in a restricted channel must be limited to that which will not cause too great injury to the side slopes.

5. The speed must not be great enough to make the ship unmanageable.

6. The speed in narrow channels must be reduced when meeting other ships.

7. A lower rate of speed will be required in curves than on tangents by reason of the greater difficulty of steering the ship.

As already stated, some of these conditions can only be discussed in a general way with results only approximately correct; others can be evaluated wholly or in part from the results of observation, as will appear in what follows.

(1) *Retardation in shoal water.*—This depends on the form of the ship, so much so that the design of ship is varied with regard to the depth of water in which it is to navigate. Observations made recently on the freight steamship *Angeline* in the deep water of Lake Huron and the shoal water of Lake St. Clair indicate that the retardation is about 18 per cent. The depth of water under the keel was about 2 feet 10 inches, no allowance being made for the settlement of a ship in the water, which always occurs when the water is shoal. The log of a recent trip of the steamship *Senator*, from Detour to Detroit, shows a speed of 12.2 miles in open lake and about 16 per cent less in the shoal water of Lake St. Clair. The depth of water under the ship's keel, without allowance for settlement, was about 2 feet. These results are not so concordant as might have been expected, and the need of further observations is manifest. The estimated reduction of speed of the *Angeline* is derived by adding to an observed reduction of 11 per cent in the speed of revolution of the wheel a further 7 per cent for an estimated increase of slip. In the case of the *Senator*, the time was observed for the passage across Lake Huron, giving an accurate determination for speed in open lake and for the passage from the foot of St. Clair Flats Canal to Detroit. The latter includes 15 miles of shoal water, where the current is imperceptible, and 8 miles at the foot of Lake St. Clair and in Detroit River, where the water is 25 to 40 feet deep and the current about 1.8 miles per hour.

The log record would have been more satisfactory if the time had also been taken at the end of the 15 miles of shoal water in Lake St. Clair. The reduction of wheel speed of the *Senator* was about the same as for the *Angeline*, and it is therefore probable that the increase of slip of wheel of the latter ship was overestimated and the actual reduction of speed on entering shoal water was probably less than 18 per cent. For this discussion, however, it is deemed best to be on the safe side, and the reduction of speed is taken at 20 per cent. On this basis the speed of the ship will be reduced from $12\frac{1}{2}$ miles to 10 miles per hour on entering shoal water. It should be noted that the depth

of the channel for the lake ship is assumed to be 2 feet more than the draft of the ship, while the depth of channel for the ocean ship is 3 feet more than its draft. Obviously, the excess for the deeper-draft ship should be the greater, but the additional 1 foot is doubtless more than needed to equalize the conditions.

In designing the 21-foot waterway it was found that in the lower portion of the Mohawk Valley, where a slack-water navigation is intended, a deep channel will be cheaper than a shallow one. This led to the adoption of a 30-foot channel in this section for both the 21-foot and 30-foot navigation. The reduction of speed sustained by a ship drawing 19 feet will be much less in water 30 feet deep than in water 21 feet deep. While there are no available data to determine what the difference will be, it appears safe to assume that the reduction of speed of a ship drawing 19 feet will not be more than 10 per cent when passing from deep lake into 30 feet of water of unlimited width. If the speed is 12½ miles per hour in deep, open water, its speed in water 30 feet deep will be on this basis 11¼ miles per hour.

These reductions of speed for the several channels and type ships appear in column 5 of Tables III, IV, and V.

(2) *Retardation from back flow.*—The resistance to the motion of the ship due to the friction of the water along its sides must depend directly on the relative movement of the ship and water. The case is analogous to that of a ship moving against a river or tidal current in a large waterway, where the speed of the ship past a fixed land point is less than the speed through the water, the difference being practically the velocity of the current. In a restricted waterway other conditions are set up, which will be discussed further on, but the direct effect of the back flow must be to reduce the speed of the ship past a fixed land point by an amount very nearly equal to the velocity of the back flow. It is assumed for this discussion that the retardation is exactly equal to the velocity of back flow, and on this basis the following formulæ are deduced:

Let A=area of the cross section of the waterway.

$a$=area of the cross section of the ship below water line.

$r=\frac{A}{a}$.

$V_1$=speed of ship past a fixed land point.

$V_2$=mean velocity of back flow.

$V$=speed of ship through the water.

Then—

$$V_2=\frac{a}{A-a}\times V_1=\frac{V_1}{r-1} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$V_1=V-V_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$V_2=\frac{a}{A}\times V_1=\frac{V}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The reductions of speed of the type ships in the several channels of the deep waterway are entered in column 7 of Tables III, IV, and V. They are to be deducted from the speed of the same ships in shoal water of unlimited width.

(3) *Retardation from end resistance.*—When a ship moves in open sea, the water is raised at the bow and depressed at the stern. This causes a pressure, opposing the ship's motion proportional to this difference of level. In a channel of restricted cross section this piling up of water ahead and depression astern of the ship are much increased. We are not here concerned with the amount of this end resistance in open sea; it answers our needs for the discussion if we can determine how much greater it is in a restricted channel than in open sea. For this purpose we have only to consider those conditions of a ship's motion in a restricted channel which differ from those in open sea.

In a restricted channel the moving ship, pushing the water before it, disturbs the equilibrium of the water in the channel and the back flow past the ship tends to restore it. The theoretical head required to produce and maintain this back flow can be computed readily. The pressure opposing the ship's motion resulting from this head is due solely to the changed conditions when the ship passes from open sea into the restricted channel, and is therefore pertinent in this discussion.

Weisbach gives a formula for determining the resistance to the motion of a ship through water. The formula is

$$P = F h y,$$

in which $h$ is the head due to the speed of the ship, $y$ is the weight of a unit of volume of water, F is a constant depending on the form of the ship, and P the resulting effective resistance per unit of immersed cross section of the ship. He makes F = 0.12 to 0.20 for river steamers and 0.05 to 0.10 for large ocean ships. The ships which will traverse the deep waterway will probably have full lines, and for this discussion F is taken equal to one-sixth. Taking $y = 62\frac{1}{2}$ pounds (the weight of a cubic foot of water), the total resisting pressure

$$= Pa = \frac{62.5\ h}{6} \times a = 10.42\ h\ a \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and the work done when the ship moves $V_1$ miles per hour is

$$10.42\ h\ a \left(\frac{5280}{3600} V_1\right) \frac{1}{550} \text{ H. P.} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

To determine $h$, let $V_3$ = velocity of back flow in feet per second $= \frac{44}{30} V_2$; $h_1$ = head required to produce $V_3$; and $h_2$ = head required

to maintain $V_3$ in the channel formed between the ship and the sides and bottom of the waterway; then—

$$h_1 + h_2 = h$$
$$h_1 = \frac{V^2_3}{2g} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$
$$h_2 = l\,s$$

in which $l$ = length of ship and $s$ = slope of back flow.

From the ordinary formula for velocity of flow in open channels

$$s = \frac{V^2_3}{C^2 R} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

in which R = hydraulic radius and C = constant, taken in this case = 80.

From the foregoing the horsepower required to overcome the end resistance is easily computed; subtracting this from the total horsepower of the ship's engines, the remainder is available for maintaining the speed of the ship. Applying this to the case of the large-type ship in the standard 30-foot channel (Table III), the horsepower required to overcome the end resistance is 84. Deducting this from the assumed engine capacity of the ship, 3,200 horsepower (see Table I), the remainder, 3,116 horsepower, is available to move the ship. Assuming that the power varies as the cube of the speed (known to be nearly correct), and obtaining from Table III the approximate speed of this ship in the standard 30-foot channel—8.04 miles per hour—the following proportion may be written:

$$3200 : 3116 : : (8.04)^3 : x^3 = (7.97)^3$$

in which $x$=speed after allowing for end resistance. The loss of speed on this account is therefore less than 0.1 foot in the worst case, and no correction need be applied on account of end resistance.

(4) *Limit of speed to avoid undue injury to side slopes of channel.*—In a narrow channel it may be necessary to restrict speed to avoid too destructive action on the channel banks. Some degree of injury is practically unavoidable and is to be met by a maintenance charge. On the Suez, Amsterdam, Kiel, and Manchester canals the limit of speed is fixed with reference to injury to banks. The following data are derived from these canals and are pertinent.

*Suez Canal.*—The highest speed allowed in the canal sections is variously given as 10 kilometers (=5.4 knots=6.2 statute miles) and 5 knots (=5¾ statute miles) per hour. The former is probably correct.

The cross section of the canal before the enlargement now going on was about 3,700 square feet, as nearly as can be ascertained from the data at hand. The largest steamers traversing it are those of the Peninsular and Oriental Company. One of the older ships of this line, which probably traversed the canal before the enlargement, had

a length of 450 feet, a beam of 52 feet, and a draft of 23 feet. Applying formula (1)

$$V_2=\frac{52\times 23}{3700-52\times 23}\times 6.2=2.96 \text{ miles per hour}$$
$$=4.34 \text{ feet per second}$$

as the velocity of back flow when this ship traverses the canal at the highest speed permitted. The soil is a sand easily moved, and the cost of maintenance has always been great. The channel is being enlarged about 50 per cent.

*Amsterdam Canal.*—The original cross section was about 3,200 square feet in area. It has been widened and deepened from time to time, and its present cross section is not far from 4,000 square feet. The speed permitted is 9 kilometers per hour (=5.6 statute miles per hour=8.2 feet per second). The largest boats traversing this canal are those of the Holland-America Line. One of the largest of these, the *Werkendam*, is 39 feet-beam and 23 feet-draft, having a wet section of about 880 square feet. These data give $V_3=\frac{880}{4000-880}\times 8.2=2.3$ feet per second. The slopes are sand in many places.

*Kiel Canal.*—The area of the cross section is about 4,100 square feet. The limit of speed permitted is 5.4 knots=6.2 statute miles per hour=9.1 feet per second. The chief engineer states that the largest ships make only 4 knots per hour.

*Manchester Canal.*—The area of cross section in earth is about 4,400 square feet. Ships are towed, probably on account of the sharp curves at Runcorn. The largest ships, having a cross section of about 1,200 square feet, giving $r=3.7$, are allowed to make 6 miles per hour (=8.8 feet per second), giving $V_3=\frac{1200}{4400-1200}\times 8.8=3.3$ feet per second. The banks are generally firm clay. Smaller boats are allowed greater speed, up to 13 miles per hour. At these high speeds much damage is done to the slopes near the water line by wave action.

The speed of back flow in all these cases is at times much greater than just stated on account of currents. In the Suez and Manchester canals the currents caused by tidal action exceed 3 miles per hour. A ship moving against the current will be forced as near the permitted speed as the power of the engines will permit, so that ships with high power may cause a back flow exceeding the calculated one considerably. The St. Clair Flats Canal affords an example of this.

The observations recently made there showed a calculated maximum for $V_2$ of 1.18 miles per hour, to which is to be added the normal current velocity of 1.7 miles, making a total velocity of 2.89 miles per hour, or 4.2 feet per second.

Much stronger currents exist in the vicinity of the ships' propellers. They erode the bottom and part of the eroded material gradually works toward the sides of the channel, filling in at the bottom of each side slope. This action is often noted, but its duration at any point is so short that it is not of great practical importance.

In the deep waterway there will be no tidal action, but in many places where streams are to be taken into the channel currents will be produced. This will be the case particularly in the Mohawk Valley, where a slack-water navigation is to be provided. The channel in this valley has been designed of such a cross section that only very rare floods, occurring not oftener than once in twenty or thirty years, will create a current of as much as 4 feet per second. While it is not likely that the channel will be navigated during these violent floods, currents exceeding 2 feet per second will occur frequently.

In fixing the permissible limit of velocity of back flow there can be no safer guide than experience. On the foreign ship canals the back flow has been found excessive, especially at Suez, where more experience has been gained than elsewhere, and the channel is being enlarged to reduce it. Giving this experience due weight, and remembering that the river currents in the deep waterways will produce currents analogous to the tidal currents in the Suez and Manchester canals, it seems judicious to so restrict the speed of the type ships that the calculated back flow shall not exceed 3 feet per second. Currents will occasionally increase this.

The calculated back flow in the several channels is given in Tables III, IV, and V, in column 7, headed "Retardation due to back flow." In the standard section of the 30-foot waterway the back flow, as given in Table III, is 1.96 miles per hour, or $1.96 \times 1.467 = 2.88$ feet per second, which is within the limit. In all other cases the velocity is less. This means that the type ships, having engines of only sufficient power to propel them 12½ miles in the open sea, can not attain in the waterway a speed sufficient to injure the banks unless currents exist in the channel. These currents will usually be very slight. Stronger currents, capable, when combined with back flow, of washing the banks, will be of short duration.

It remains to be seen whether ships considerably larger than the type ships would cause inadmissible velocities. A ship 65 feet by 27 feet, moving in a 30-foot channel of 203 feet bottom width at the rate of 8 miles per hour, will produce a back flow of 3.3 feet per second. This velocity, occurring rarely, would be permissible. A ship 58 feet by 19 feet, moving in a 21-foot channel of 215 feet bottom width at the rate of 8 miles per hour, will produce a back flow of 2.9 feet per second, which is less than the assumed limit.

(5) *Reduction of speed on account of increased difficulty of steering a ship in a restricted waterway.*—It is difficult to evaluate this condition. Obviously it depends much on the ability of the pilot and much on the model of the ship. It is more likely to be important in narrow channels than in wide ones and of greater importance as the clearance between the ship's bottom and the bed of the channel decreases.

The ship assumed in this discussion for the 30-foot waterway has a clearance of 3 feet between the ship's bottom when at rest and the

bed of the channel, a clearance which will be diminished to some extent when the ship moves. This clearance is rather more than is usual under large ships in canals. In the 21-foot waterway it is assumed that the clearance under the ship at rest will be 2 feet, which corresponds more nearly with observed cases.

Table II, which follows, gives a list of vessels observed recently in the St. Clair Flats Canal. It includes boats of a carrying capacity of 6,000 to 7,000 tons. Several of the larger ones were loaded to within less than 2 feet of the bed of the channel. It will be noted that the actual speeds are generally less than those in Tables III, IV, and V, although a few are about the same, as, for example, the *Northern Light*, a freight boat, and the passenger ship *Northland*. This is a crowded waterway, and the speeds are limited by regulation to 8 miles per hour, a limit often exceeded. There seems to be no doubt that this limit is safe. The waterway is short, and there is little time to be gained by a higher limit of speed; if it were longer, permitting an appreciable saving of time with higher speeds, they would doubtless be attempted.

TABLE II.—*Speeds of loaded boats, without tows, in St. Clair Flats Canal, in statute miles per hour.*

[Section of canal = 296 × 19.5 = 5,772 square feet. Deduct for shoal water near piers, say 72 square feet. Net cross-section = 5,700 square feet. Current in channel, 1.71 miles per hour.]

| Ship. | Gross tonnage. | Net tonnage. | Draft. Fore. | | Draft. Aft. | | Beam. | Area of immersed cross section. | Ratio of cross section of ship to cross section of channel. | Speed of ship corrected for current in the channel ($V_1$). | Back flow. | Speed in water ($V_1$). | With (W) or against (A) current. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Ft.* | *in.* | *Ft.* | *in.* | | *Sq. ft.* | | *Miles.* | | | |
| Fred Mercur | 1,224 | 966 | 15 | 4 | 15 | 9 | 35 | 534 | 1:10.7 | 6.48 | 0.67 | 7.15 | W. |
| J. N. Glidden | 1,322 | 1,110 | 16 | 6 | 16 | 6 | 35 | 560 | 1:10.2 | 6.02 | .66 | 6.68 | W. |
| Topeka | 1,376 | 1,111 | 16 | 10 | 16 | 10 | 36 | 588 | 1: 9.7 | 6.56 | .75 | 7.31 | W. |
| R. P. Fitzgerald | 1,681 | 1,175 | 17 | 2 | 17 | 2 | 38 | 633 | 1: 9.0 | 9.41 | 1.18 | 10.59 | A. |
| Oceanica | 1,490 | 1,241 | 14 | 6 | 14 | 6 | 37 | 518 | 1:11.0 | 5.24 | .52 | 5.76 | W. |
| Vulcan | 1,759 | 1,366 | 17 | 4 | 17 | 4 | 38 | 643 | 1: 8.9 | 6.31 | .80 | 7.11 | W. |
| Conemaugh | 1,609 | 1,453 | 16 | 0 | 16 | 0 | 36 | 558 | 1:10.2 | 5.83 | .64 | 6.47 | W. |
| Lehigh | 1,704 | 1,503 | 15 | 0 | 15 | 0 | 36 | 522 | 1:10.9 | 8.17 | .83 | 9.00 | A. |
| R. E. Schuck | 1,867 | 1,523 | 17 | 0 | 17 | 0 | 41 | 676 | 1: 8.4 | 6.89 | .82 | 7.71 | W. |
| F. H. Prince | 2,047 | 1,547 | 14 | 3 | 14 | 3 | 42 | 577 | 1: 9.9 | 6.66 | .75 | 7.41 | W. |
| Joliet | 1,921 | 1,596 | 17 | 7 | 17 | 7 | 38 | 649 | 1: 8.8 | 8.54 | 1.09 | 9.63 | W. |
| La Salle | 1,921 | 1,596 | 17 | 5 | 17 | 5 | 38 | 643 | 1: 8.9 | 5.83 | .74 | 6.57 | W. |
| Majestic | 1,985 | 1,609 | 16 | 9 | 17 | 0 | 40 | 660 | 1: 8.6 | 8.64 | 1.16 | 9.80 | W. |
| Mohawk | 2,357 | 1,616 | 15 | 0 | 15 | 0 | 41 | 594 | 1: 9.6 | 8.80 | 1.02 | 9.82 | W. |
| City of London | 2,005 | 1,675 | 16 | 8 | 17 | 2 | 41 | 683 | 1: 8.3 | 7.63 | 1.05 | 8.63 | A. |
| Mahoning | 2,189 | 1,704 | 15 | 0 | 16 | 0 | 40 | 620 | 1: 9.2 | 8.41 | 1.03 | 9.44 | W. |
| Republic | 2,316 | 1,877 | 17 | 6 | 17 | 6 | 40 | 680 | 1: 8.4 | 6.36 | .86 | 7.22 | W. |
| North Star | 2,476 | 1,885 | 16 | 0 | 16 | 0 | 40 | 620 | 1: 9.2 | 6.81 | .83 | 7.64 | W. |
| Northern Light | 2,476 | 1,885 | 15 | 4 | 15 | 4 | 40 | 597 | 1: 9.5 | 11.41 | 1.35 | 12.76 | W. |
| Onoko | 2,164 | 1,933 | 16 | 6 | 16 | 6 | 38 | 608 | 1: 9.4 | 6.34 | .75 | 7.09 | W. |
| Owego | 2,611 | 1,940 | 16 | 0 | 17 | 0 | 41 | 676 | 1: 8.4 | 7.86 | 1.06 | 8.92 | W. |
| Chemung | 2,615 | 1,943 | 16 | 0 | 16 | 0 | 41 | 635 | 1: 9.0 | 7.62 | .95 | 8.57 | A. |
| Thomas Maytham | 2,329 | 1,972 | 17 | 2 | 17 | 2 | 41 | 683 | 1: 8.3 | 5.16 | .71 | 5.87 | W. |
| Ma-aba | 2,431 | 1,992 | 16 | 5 | 16 | 5 | 40 | 637 | 1: 9.0 | 6.21 | .78 | 6.99 | A. |
| Kearsarge | 3,092 | 2,721 | 17 | 6 | 17 | 6 | 44 | 748 | 1: 7.6 | 6.36 | .97 | 7.33 | W. |
| Penobscot | 3,502 | 2,864 | 17 | 0 | 17 | 0 | 44 | 726 | 1: 7.8 | 5.11 | .75 | 5.86 | W. |
| Senator | 4,048 | 3,178 | 17 | 2 | 17 | 2 | 45 | 750 | 1: 7.6 | 6.70 | 1.02 | 7.72 | W. |
| Presque Isle | 4,578 | 3,570 | 17 | 8 | 18 | 0 | 50 | 875 | 1: 6.5 | 6.13 | 1.12 | 7.25 | W. |
| Crescent City | 4,213 | 3,675 | 17 | 1 | 17 | 1 | 48 | 796 | 1: 7.2 | 7.36 | 1.18 | 8.54 | W. |
| Passenger boats: | | | | | | | | | | | | | |
| Northland | | 2,339 | 13 | 5 | 14 | 5 | 44 | 612 | 1: 9.3 | 9.99 | 1.20 | 11.19 | W. |
| Arundel (fastest observed) | | 257 | | | | | 26 | | | 15.41 | | | W. |
| Idlewild | | 284 | 5 | 8 | 5 | 8 | 26 | 134 | 1:42.5 | 13.02 | .31 | 13.33 | W. |

NOTE.—Six inches deducted from maximum draft in calculating crossection of ships.

The Suez Canal affords a precedent even more pertinent. In the original canal, having a bottom width of 72 feet, a speed of 6.2 statute miles per hour was fixed, rather with regard to the effect of wash on the channel banks than to safety of the ship itself. If it were not for the injurious effects of wash on the banks a higher speed limit would probably have been fixed. There can be no doubt that a speed of 8 miles per hour in the regular channel of the deep waterway is relatively less than the speed permitted in the narrow channel of the Suez Canal.

In the 300-foot channels excavated in open water in the St. Marys River, boats formerly ran 12 to 13 miles per hour. This is a crowded navigation, the number of boats per day being about 100. Collisions were frequent, and it was thought necessary to establish and enforce rules limiting speeds to 9 miles per hour.

In the deep waterway the speed of the type ship in the 30-foot channel of 300-foot bottom width would be $10 - 1.44 = 8.56$ miles per hour (see Table III) and in the 21-foot waterway of 300-foot bottom width $10 - 1.36 = 8.64$ miles per hour (Table V), both within the limit established in the St. Marys River. An inquiry addressed to Mr. Joseph Ripley, the assistant engineer in charge of the St. Marys River and St. Marys Falls Canal, elicited the following reply, extracted from a letter dated April 13, 1899:

> The highest permissible speed through the present cuts at Little Rapids and Hay Lake depends on number, size, and draft of boats, and whether single or with tows. For the commerce of last season, which averaged nearly 110 boats per day for that part of the river, with about 10 per cent of them over 400 feet in length, the speed should not exceed 9 miles per hour, slowing to about 6 miles when meeting boats. Under the above conditions there were two collisions in the Little Rapids cut last season. For width of 600 feet, with earth banks, the speed could be safely increased to 11 or 12 miles per hour, checking to 8 miles when meeting tows.

The channel at the Little Rapids, to which Mr. Ripley refers, has proved troublesome on account of the strong current through it and cross currents caused by escape of water into lateral channels. Currents as strong as these would occur in the deep waterway only during very unusual floods. These floods, rare as they are, occur almost without exception during the spring break-up, before the opening of lake navigation. The experience at the Little Rapids does not apply to the movement of ships in slack water or in very light currents—the latter in the conditions which will exist in the deep waterway—and under such conditions the examples which have been cited support strongly the speeds calculated for the type ships in their respective waterways. These speeds being within the limit of successful practice need no further reduction.

The ship of 19-foot draft in the 30-foot channel will have at least 10 feet of water under its keel when in motion in the waterway, and will steer as well, practically, as in open sea.

The speeds thus far discussed refer to a straight channel, with no meeting ships. They need correction for reduced speed at meeting points and on curves.

(6) *Reduction of speed at meeting points.*—On the Suez, the Manchester, and other ship canals, when two large ships are about to meet, one ties up until the other passes. This will not be necessary in the greatly wider deep waterway. The speed of both ships, however, will have to be reduced in the narrow channels. The proper speed at the meeting point will depend obviously on the width of the channel, the greater the width the greater the permissible speed at the meeting point. In a channel 600 feet wide no reduction of speed will be necessary. In the 300-foot wide channels of the St. Marys River a reduction of speed of from 9 to 6 miles per hour has been found sufficient, but in most places the channel is dredged through shoal water, and the escape of the water laterally from the channel may possibly facilitate the passing of ships. While it has not been proven that the movement of ships is thus facilitated, it is believed some weight should be given to this consideration. It will be assumed, therefore, that the speed would be reduced one-half at the meeting point in a channel 200 feet wide at bottom. In wider channels the reduction will be taken as diminishing uniformly with increase of bottom width, becoming zero when the bottom width is 600 feet.

It would seem that if two ships of 19 feet draft should meet in the 30-foot channel of the regulated Mohawk a greater speed at meeting points would be permissible. This is certainly true, but to make it available it would be necessary to have different regulations for different classes of ships, which would be objectionable. The same law of reduction is, therefore, applied in this case as in the others.

In order to measure the effect of delays at meeting points it is necessary to assume a navigation period and a traffic. For the present discussion the number of days of navigation per year will be assumed at 237. In calculating the amount of water required for the supply of the summit level it was assumed that the annual tonnage through the canal would be 25,000,000, carried in 8,333 ships, giving 35.2 ships per day, or 1 in 41 minutes. These figures are for the 30-foot waterway. For the 21-foot waterway the same traffic may be assumed to be carried in 10,000 ships, giving 42.2 ships per day, or 1 in 34 minutes. The maximum delay from meetings will occur if all ships are met singly, and if this is assumed the resulting delay will be greater than the truth and on the safe side. The number of ships assumed is also on the safe side, because it represents the full capacity of the canal with ships averaging 3,000 and 2,500 tons, respectively, in the two channels. The full capacity is not likely to be reached at once and the ships will probably be larger, thus reducing the number of ships and number of meetings for the assumed annual traffic.

When ships are approaching a meeting point they will begin reduc-

ing speed when some distance apart, this distance depending on the speed at which they are moving and the reduced speed to be attained.

In order to ascertain the time required to reduce or increase speed an informal inquiry was made of Mr. Ripley, who prepared a form of report as a circular for distribution among masters of vessels. About 160 of these reports have been made and furnished to the Board by Mr. Ripley. From these reports those of 17 of the larger boats, carrying loads and moving singly (without tows), have been used to determine the rate of change of speed. The reports show both time and estimated distance required to attain full speed from a stop and also to stop from full speed; but in many cases the ships' wheels were used to stop speed, which would generally be impracticable in a narrow channel. Rejecting those cases where the use of the wheel was noted or was obvious, the rate of reduction of speed seems to be about the same as the rate of increase. For the reason that there still remained some doubt as to the use of the wheel in stopping it has seemed best to base the rate of change of speed wholly on the records relating to increase of speed.

As might be expected, the estimates of time and distance made by different sailing masters vary greatly. Without exact observations it is not easy to decide when a ship has attained full speed. It is believed, however, that a sufficient number of observations have been taken to eliminate any important error.

Taking the entire set of 17 observations, the average rate of increase of speed from stop to full speed is 1 mile per hour while the ship traverses 440 feet. As the time was also noted, the mean time required for an increase of speed of 1 mile per hour is found to be nine-tenths of a minute. In this interval a ship moving 12 miles per hour—the average full speed of the boats observed—would traverse a distance of 396 feet. This agrees well enough with the former determination.

Rejecting 8 of the observations—the lowest four and the highest four—the remaining 9, reduced in the same manner, give averages of change of speed of 1 mile per hour in 350 and 336 feet, respectively. This result is probably more nearly correct than the former. In order to be on the safe side the distance of 400 feet is here accepted as required for a change of speed of 1 mile per hour.

This conclusion is based on the assumption that the change of speed varies directly with the distance traversed. It may seem that the higher the speed the greater the distance to be traversed for an increase of 1 mile per hour. This is very probably the case. On the other hand, when the engines are stopped it is probable that the rate diminishes more rapidly at first than after the speed has been much reduced. If this is true, the two variations from the mean tend to offset each other, and the average distance deduced above will not be much in error for the entire cycle of reduction and increase.

In order to produce the minimum delay at a meeting point the ship's

engines should be stopped at the exact moment required to permit the proper reduction of speed to be attained when the bow of the ship is opposite the bow of the meeting ship. The engines should be started at full speed at the moment when the ships are clear and not before, or when each ship has moved its length. For the type ship in the 30-foot channel this distance is 550 feet. It will not be practicable, however, to realize this ideal movement. The pilot will not be able to judge with the required precision either the distance to the other boat or the speed of his own, and it is probable that the required reduced rate will be attained before the ships meet. As a basis for calculation, it is assumed that after the required reduction of speed has been attained the ship will continue under check at this rate for a distance of 1,000 feet, and will then proceed with engines at full speed. This assumption will be applied to both type ships. The calculations are made in the following manner:

Required the delay to a ship in the standard 30-foot channel:

The full speed in this channel is 8.04 miles per hour. (See Table III.) The reduction of speed will be

$$\tfrac{1}{2}\times 8.04\times\frac{600-203}{600-200}=3.99 \text{ miles per hour,}$$

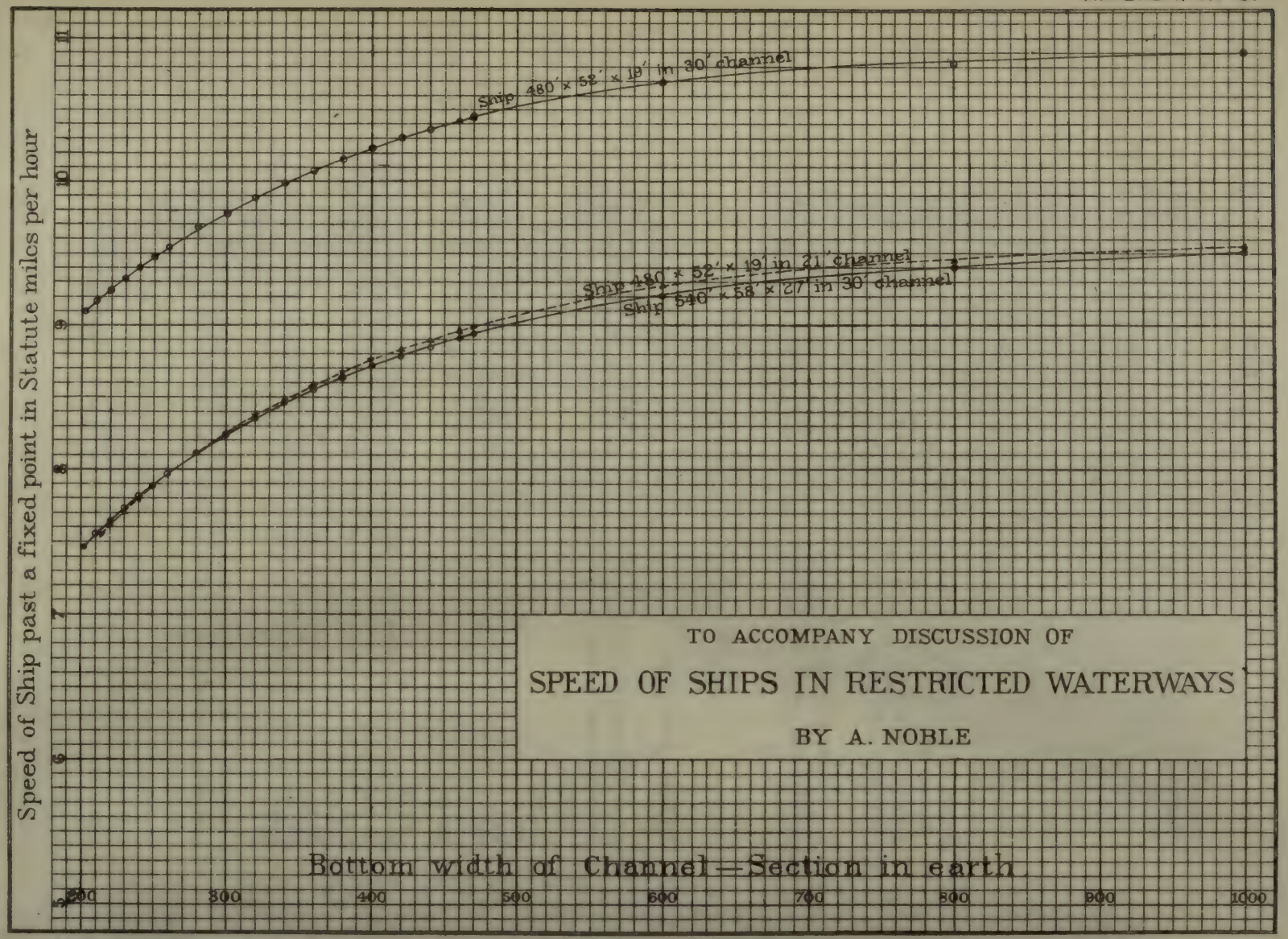
and the minimum speed at meeting point will be $8.04-3.99=4.05$ miles per hour.

The speed is to be reduced from 8.04 to 4.05 miles per hour and to be maintained at this rate for a distance of 1,000 feet and then increased to 8.04 miles per hour.

| | Feet. |
|---|---|
| Distance to be traversed while reducing speed, 400×3.99 | 1,596 |
| Distance to be traversed at minimum speed | 1,000 |
| Distance to be traversed while increasing speed 400×3.99 | 1,596 |
| Total | 4,192 |

| | Minutes. |
|---|---|
| Time required for 1,596 feet at ½ (8.04+4.05) miles per hour | 3.00 |
| Time required for 1,000 feet at 4.05 miles per hour | 2.81 |
| Time required for 1,596 feet at ½ (8.04+4.06) miles per hour | 3.00 |
| Total | 8.81 |
| Time required to traverse 4,192 feet at 8.04 miles per hour | 5.92 |
| Time lost | 2.89 |

This loss of time will occur at each meeting in the given channel. According to the assumption, meetings will occur every 41 minutes. The loss of time is therefore $\frac{2.89}{41}$ of the total. The distance passed over by the ship will be $\frac{41-2.89}{41}=\frac{38.11}{41}$ of the distance it would move


Speed of Ship past a fixed point in Statute miles per hour
Ship 480' x 52' x 19' in 30' channel
Ship 480' x 52' x 19' in 21' channel
Ship 540' x 58' x 27' in 30' channel
TO ACCOMPANY DISCUSSION OF
SPEED OF SHIPS IN RESTRICTED WATERWAYS
BY A. NOBLE
Bottom width of Channel — Section in earth
200
300
400
500
600
700
800
900
1000
JULIUS BIEN & CO. PHOTO LITH

in 41 minutes if there were no meetings. Its mean speed is therefore $\frac{38.11}{41}$ of the speed it would have if there were no meetings, or

$$8.04 \times \frac{38.11}{41} = 7.47 \text{ miles per hour} = \text{average speed of ship.}$$

In this manner the speeds in column 10 of Table III have been calculated. In column 10 of Table IV are the speeds in the 30-foot waterway in the Mohawk Valley if it forms part of a 21-foot navigation. In column 10 of Table V are the speeds in the 21-foot waterway. The speeds in Tables IV and V are calculated in precisely the same manner as in Table III, except that meetings for the 21-foot navigation are taken as occurring once in 34 minutes instead of once in 41 minutes. These are the average speeds on tangents and require correction on curves.

The tabulated speeds in column 10 of the tables are reproduced graphically on fig. 1, where the abcissas are the bottom widths of channel and the ordinates are speeds.

TABLE III.—*Speed, in statute miles per hour, of ship 540 feet long over all, 58 feet beam, 27 feet draft, in 30-foot channel.*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Bottom width of channel | A | $r$ | Speed of ship in open sea. | Loss of speed on entering shoal water. | Speed in shoal water of unlimited width. | Retardation due to back flow in restricted channel.[1] | Full speed on tangents. | Reduction of average speed caused by meetings. | Average speed of ship on tangents. |
| *Feet.* | | | | | | | | | |
| 203 | 7,990 | 5.10 | 12.5 | 2.5 | 10 | 1.96 | 8.04 | 0.57 | 7.47 |
| 210 | 8,200 | 5.24 | 12.5 | 2.5 | 10 | 1.91 | 8.09 | .54 | 7.55 |
| 220 | 8,500 | 5.43 | 12.5 | 2.5 | 10 | 1.84 | 8.16 | .52 | 7.64 |
| 230 | 8,800 | 5.62 | 12.5 | 2.5 | 10 | 1.78 | 8.22 | .49 | 7.73 |
| 240 | 9,100 | 5.81 | 12.5 | 2.5 | 10 | 1.72 | 8.28 | .47 | 7.81 |
| 250 | 9,400 | 6.00 | 12.5 | 2.5 | 10 | 1.67 | 8.33 | .44 | 7.89 |
| 260 | 9,700 | 6.19 | 12.5 | 2.5 | 10 | 1.62 | 8.38 | .41 | 7.97 |
| 280 | 10,300 | 6.58 | 12.5 | 2.5 | 10 | 1.52 | 8.48 | .37 | 8.11 |
| 300 | 10,900 | 6.96 | 12.5 | 2.5 | 10 | 1.44 | 8.56 | .33 | 8.23 |
| 320 | 11,500 | 7.34 | 12.5 | 2.5 | 10 | 1.36 | 8.64 | .29 | 8.35 |
| 340 | 12,100 | 7.73 | 12.5 | 2.5 | 10 | 1.29 | 8.71 | .25 | 8.46 |
| 360 | 12,700 | 8.11 | 12.5 | 2.5 | 10 | 1.23 | 8.77 | .22 | 8.55 |
| 380 | 13,300 | 8.49 | 12.5 | 2.5 | 10 | 1.18 | 8.82 | .19 | 8.63 |
| 400 | 13,900 | 8.88 | 12.5 | 2.5 | 10 | 1.13 | 8.87 | .16 | 8.71 |
| 420 | 14,500 | 9.26 | 12.5 | 2.5 | 10 | 1.08 | 8.92 | .14 | 8.78 |
| 440 | 15,100 | 9.64 | 12.5 | 2.5 | 10 | 1.04 | 8.96 | .11 | 8.85 |
| 460 | 15,700 | 10.03 | 12.5 | 2.5 | 10 | 1.00 | 9.00 | .09 | 8.91 |
| 470 | 16,000 | 10.22 | 12.5 | 2.5 | 10 | .98 | 9.02 | .08 | 8.94 |
| 600 | 19,900 | 12.71 | 12.5 | 2.5 | 10 | .79 | 9.21 | .00 | 9.21 |
| 800 | 25,900 | 16.54 | 12.5 | 2.5 | 10 | .60 | 9.40 | .00 | 9.40 |
| 1,000 | 31,900 | 20.37 | 12.5 | 2.5 | 10 | .49 | 9.51 | .00 | 9.51 |

[1] Equals velocity of back flow.

TABLE IV.—*Speed, in statute miles per hour, of ship 480 feet long over all, 52 feet beam, 19 feet draft, in 30-foot channel.*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Bottom width of channel. | A | $r$ | Speed of ship in open sea. | Loss of speed on entering shoal water. | Speed in shoal water of unlimited width. | Retardation due to back flow in restricted channel.[1] | Full speed on tangents. | Reduction of average speed caused by meetings. | Average speed of ship on tangents. |
| *Feet.* | | | | | | | | | |
| 203 | 7,990 | 8.09 | 12.5 | 1.25 | 11.25 | 1.39 | 9.86 | 0.76 | 9.10 |
| 210 | 8,200 | 8.30 | 12.5 | 1.25 | 11.25 | 1.35 | 9.90 | .73 | 9.17 |
| 220 | 8,500 | 8.60 | 12.5 | 1.25 | 11.25 | 1.31 | 9.94 | .70 | 9.24 |
| 230 | 8,800 | 8.90 | 12.5 | 1.25 | 11.25 | 1.26 | 9.99 | .66 | 9.33 |
| 240 | 9,100 | 9.21 | 12.5 | 1.25 | 11.25 | 1.22 | 10.03 | .63 | 9.40 |
| 250 | 9,400 | 9.51 | 12.5 | 1.25 | 11.25 | 1.18 | 10.07 | .59 | 9.48 |
| 260 | 9,700 | 9.82 | 12.5 | 1.25 | 11.25 | 1.15 | 10.10 | .56 | 9.54 |
| 280 | 10,300 | 10.42 | 12.5 | 1.25 | 11.25 | 1.08 | 10.17 | .49 | 9.68 |
| 300 | 10,900 | 11.03 | 12.5 | 1.25 | 11.25 | 1.02 | 10.23 | .44 | 9.78 |
| 320 | 11,500 | 11.64 | 12.5 | 1.25 | 11.25 | .97 | 10.28 | .39 | 9.89 |
| 340 | 12,100 | 12.24 | 12.5 | 1.25 | 11.25 | .92 | 10.33 | .34 | 9.99 |
| 360 | 12,700 | 12.85 | 12.5 | 1.25 | 11.25 | .88 | 10.37 | .30 | 10.07 |
| 380 | 13,300 | 13.46 | 12.5 | 1.25 | 11.25 | .84 | 10.41 | .25 | 10.16 |
| 400 | 13,900 | 14.07 | 12.5 | 1.25 | 11.25 | .80 | 10.45 | .22 | 10.23 |
| 420 | 14,500 | 14.67 | 12.5 | 1.25 | 11.25 | .77 | 10.48 | .18 | 10.30 |
| 440 | 15,100 | 15.28 | 12.5 | 1.25 | 11.25 | .74 | 10.51 | .15 | 10.36 |
| 460 | 15,700 | 15.89 | 12.5 | 1.25 | 11.25 | .71 | 10.54 | .12 | 10.42 |
| 470 | 16,000 | 16.19 | 12.5 | 1.25 | 11.25 | .70 | 10.55 | .10 | 10.45 |
| 600 | 19,900 | 20.14 | 12.5 | 1.25 | 11.25 | .56 | 10.69 | .00 | 10.69 |
| 800 | 25,900 | 26.21 | 12.5 | 1.25 | 11.25 | .43 | 10.82 | .00 | 10.82 |
| 1,000 | 31,900 | 32.29 | 12.5 | 1.25 | 11.25 | .35 | 10.90 | .00 | 10.90 |

[1] Equals velocity of back flow.

TABLE V.—*Speed, in statute miles per hour, of ship 480 feet long over all, 52 feet beam, 19 feet draft, in 21-foot channel.*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| Bottom width of channel. | A | $r$ | Speed of ship in open sea. | Loss of speed on entering shoal water. | Speed in shoal water of unlimited width | Retardation due to back flow in restricted channel.[1] | Full speed on tangents. | Reduction of average speed caused by meetings. | Average speed of ship on tangents. |
| *Feet.* | | | | | | | | | |
| 215 | 5,497 | 5.54 | 12.5 | 2.5 | 10 | 1.81 | 8.19 | 0.64 | 7.55 |
| 220 | 5,602 | 5.67 | 12.5 | 2.5 | 10 | 1.76 | 8.24 | .63 | 7.61 |
| 230 | 5,812 | 5.88 | 12.5 | 2.5 | 10 | 1.70 | 8.30 | .60 | 7.70 |
| 240 | 6,022 | 6.09 | 12.5 | 2.5 | 10 | 1.64 | 8.36 | .57 | 7.79 |
| 250 | 6,232 | 6.31 | 12.5 | 2.5 | 10 | 1.58 | 8.42 | .53 | 7.89 |
| 260 | 6,442 | 6.52 | 12.5 | 2.5 | 10 | 1.53 | 8.47 | .50 | 7.97 |
| 280 | 6,862 | 6.94 | 12.5 | 2.5 | 10 | 1.44 | 8.56 | .45 | 8.11 |
| 300 | 7,282 | 7.37 | 12.5 | 2.5 | 10 | 1.36 | 8.64 | .40 | 8.24 |
| 320 | 7,702 | 7.79 | 12.5 | 2.5 | 10 | 1.28 | 8.72 | .35 | 8.37 |
| 340 | 8,122 | 8.22 | 12.5 | 2.5 | 10 | 1.22 | 8.78 | .31 | 8.47 |
| 360 | 8,542 | 8.65 | 12.5 | 2.5 | 10 | 1.16 | 8.84 | .27 | 8.57 |
| 380 | 8,962 | 9.07 | 12.5 | 2.5 | 10 | 1.10 | 8.90 | .23 | 8.67 |
| 400 | 9,382 | 9.50 | 12.5 | 2.5 | 10 | 1.05 | 8.95 | .19 | 8.76 |
| 420 | 9,802 | 9.92 | 12.5 | 2.5 | 10 | 1.01 | 8.99 | .16 | 8.83 |
| 440 | 10,222 | 10.34 | 12.5 | 2.5 | 10 | .97 | 9.03 | .14 | 8.89 |
| 460 | 10,642 | 10.77 | 12.5 | 2.5 | 10 | .93 | 9.07 | .11 | 8.96 |
| 470 | 10,852 | 10.98 | 12.5 | 2.5 | 10 | .91 | 9.09 | .10 | 8.99 |
| 600 | 13,582 | 13.75 | 12.5 | 2.5 | 10 | .73 | 9.27 | .00 | 9.27 |
| 800 | 17,782 | 18.00 | 12.5 | 2.5 | 10 | .56 | 9.44 | .00 | 9.44 |
| 1,000 | 21,982 | 22.25 | 12.5 | 2.5 | 10 | .45 | 9.55 | .00 | 9.55 |

[1] Equals velocity of back flow.

(7) *Reduction of speed on curves.*—The speed of the ship will be less on curves than on tangents, because the steering will be a little more difficult. Some compensation is made for this in designing the

waterway by increasing the width on curves. The reduction of speed will be less as the width of the channel increases. The speed of meeting ships may also be reduced. This is hardly likely to be the case in the narrow channels, as the speed already allowed for is barely sufficient for steerage way, but in the wider ones the reduction of speed on curves at meeting points may be appreciable. The subject does not admit of analysis; there are no reliable precedents, and the best that can be done is to make empirical rules. The following are proposed:

First. For channels of standard width, reduce the speed from Tables III IV, and V by

$$1.5 \times \text{degree of curve.}$$

Second. It is not believed that any reduction of speed will be required in channels 600 feet wide. For intermediate widths, multiply the reduction obtained by the preceding rule by the ratio:

$$\frac{600 - \text{Bottom width of channel in question.}}{600 - \text{Bottom width of standard channel.}}$$

## SUMMARY.

In the foregoing discussion two type ships have been taken, one 540 feet long, 58 feet beam, and 27 feet draft; the other 480 feet long, 52 feet beam, and 19 feet draft. The larger ship is assumed to be seagoing; the smaller ship is assumed to navigate the lakes and deep waterways to tide water, and both are to have a speed of 12.5 statute miles per hour in open sea.

The discussion then takes up the principal causes of retardation when a ship passes from open sea into a restricted channel and treats them singly, making use of recorded observations where possible and of theoretical discussion where observations are wanting.

The retardation when passing from deep open sea to shoal water of unlimited width is determined from observations in Lake Huron and Lake St. Clair. The reduction accepted for the discussion is somewhat greater than that observed, and, therefore, is on the safe side.

The retardation due to back flow and the retardation due to end resistance are treated theoretically.

The relation between speed of ship and injurious washing of slopes is treated theoretically, and the results checked by experience on several artificial waterways.

At this point the difficulty of steering a ship in a narrow channel and the danger of grounding on the side slopes is taken up and the conclusion reached, by reference to experience in other waterways, that there will be no material difficulty in this respect on tangents of the deep waterway.

The reduction of speed, which will be necessary when ships meet,

is discussed on a liberal basis of reduction of speed, and the time lost is determined from the results of recent observations in the Great Lakes.

The reduction of speed when passing from a tangent to a curve depends as much on the skill or timidity of the pilot as on anything else, and can not be analyzed. Observations are lacking, and a purely arbitrary assumption is made.

The theoretical discussions are extremely elementary and might be developed. It is not believed, however, that their usefulness for the present purpose would be enhanced.

### VALUE OF THE RESULTS.

The theoretical portion of this discussion covers so large a part of the subject and is necessarily so incomplete, both in scope and treatment, that the results would have very little value unless checked by observations. An examination of the speed curves (fig. 1) will facilitate an estimation of value of the results, and it will be advantageous to study each curve separately.

First. Ship 480 by 52 by 19 feet draft in the 21-foot channel. A channel 1,000 feet wide is obviously the equivalent of a channel of unlimited width as regards the movement of a ship. The Lake St. Clair observations show that in the shallow water of that lake, where the depth of water exceeded by about 2½ feet the draft of the boat, the loss of speed was considerably less that 20 per cent; 20 per cent was taken for this discussion to be on the safe side. The theoretical determination of retardation due to back flow gave a loss of speed due to the narrowing of the channel to 1,000 feet of 0.45 mile per hour. There can be little doubt that this is excessive. The same calculation shows a loss of speed of 0.73 mile per hour when the channel is narrowed to 600 feet, and there can be no doubt that the allowance is sufficient. It is also obvious that the permissible speed will be reduced in increasing ratio as the channel is narrowed, and therefore the curve should be convex upward. If, however, this were not true, and the reduction of speed varied in direct ratio to decrease in width, the curve from its lowest point to, say, the point corresponding with a channel width of 600 feet would be a straight line. The maximum deviation of this straight line from the platted curve is less than 0.4 mile per hour. The speed for a bottom width of 300 feet is only 0.64 more than the speed allowed by regulations in the crowded St. Clair Flats Canal, and is much less than frequently attained there. This curve, then, being checked at its lowest point by observation—being shown by observation to be a little too low at its highest point and having a logical direction between with no possibility of material error—is entitled to confidence.

Second. Ship 480 by 52 by 19 feet draft in the 30-foot channel. The difference in the position of this curve and the preceding one is due to the smaller reduction of speed for limitation of channel depth.

This ship would have 11 feet of water under the keel, and it should suffer little reduction of speed on this account. The value taken, 10 per cent, must be considerably excessive. With such a depth of water under the keel the ship would steer well. The lowest point of this curve is not so well connected with observations as the preceding one; but it may be remarked that in the Manchester Canal, which has a bottom width of only 120 feet, much higher speeds are permitted and attained by light-draft boats. While this curve is not as thoroughly checked by observation as the preceding one, it is believed to be trustworthy.

Third. Ship 540 by 58 by 27 feet draft in the 30-foot channel. The relation between this type ship and its channel are very nearly the same as the relations of the smaller type ship to the 21-foot channel. The reduction of speed on entering shoal water of unlimited width is taken at 20 per cent, which is doubtless somewhat excessive. The calculated retardation due to back flow in a channel 1,000 feet wide at bottom, 0.49 mile per hour, is doubtless somewhat excessive; in a channel 600 feet wide, the calculated retardation is 0.79 mile per hour, which is doubtless adequate. In a channel 300 feet wide, the calculated speed is 8.56 miles per hour, which is less than frequently attained in the St. Clair Flats Canal. It is obvious that this curve should also be convex upward. Taking the portion included between abscissas corresponding to bottom width of 203 and 600 feet, the maximum deviation of the speed curve from a straight line is less than 0.4 mile per hour. The error in the curve must be less than this if the speeds at the extremities of the curve are correct. The curve agrees well with the speeds permitted in the Suez Canal after allowing for the difference in channel width, and corresponds so closely in form to the curve for the smaller type in the 21-foot waterway that it is presented with considerable confidence in its correctness.

Respectfully submitted.

ALFRED NOBLE.

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

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## APPENDIX NO. 5.—PART 1.

### COMPARISON OF WATERWAYS.

The value to commerce of any waterway from the Lakes to tide water depends upon the amount and nature of the tonnage it is capable of passing, the speed at which restricted portions can be safely navigated, the sailing time between terminals for ships best adapted to its use, and the cost per ton-mile for transporting freight under normal conditions.

From these considerations it is evident that from both economic and engineering points of view the importance of the waterway will

depend upon its depth, ratio of cross section to that of the type ship which will use it, the stability of its banks, its length and location, the cost to construct, operate, and maintain it, and the indirect benefits to the territorry tributary to the route.

The waterway will consist of two distinct divisions. First, the lake waterways, connecting channels and harbors, and, second, the ship canal from the Lakes to the Atlantic.

It has been shown elsewhere that the dimensions of the latter should be such as to furnish safe and easy transit for the type of ships best adapted for the waterways connected, from which it is evident that whatever depth is to be established for the lake harbors and waterways should be made the basis of the design for any canal which may be constructed to connect such channels with the seaboard.

The cost to carry a ton of freight 1 mile in the lake traffic is a function of the original cost of improvements, annual expenditures for operation and maintenance, and of the speed, carrying capacity, fixed charges, and daily expenses of the ship in which transported.

It has been found from actual experience that the economical carrying capacity of ships depends upon the depths of harbors and channels to be used, and upon the speeds at which the waterways are to be traversed.

For the type of ships best adapted for lake traffic, speed in excess of about 12½ statute miles per hour in the open lake involves a corresponding decrease in freight capacity, or an increase in amount of fuel per mile run, either of which will increase the rate per ton mile of the freight carried.

The economical carrying capacity of a ship increases rapidly with the draft which the waterways will allow, and, since the cost of channel and harbor improvements increase rapidly with the depths to be maintained, it is important that the depth of lake channels be determined at which the cost of transportation of the lake freight will be a minimum for ships best adapted for the business and safe navigation.

The depth of water at mean stage at the foot of Lake Huron, through Lake St. Clair, and at the head of Lake Erie is from 20 to 21 feet, and, therefore, for all navigable channels over 21 feet deep the cost per foot of improvement and for maintenance will be greatly in excess of that for waterways of less depth. The conditions at the entrance of the lake harbors are such as to produce a similar effect on cost of improvement for different depths.

The cost in the past for deepening all the harbors and waterways of the lake system has been about $5,000,000 per foot of increase. From the best available data, it is estimated that for depths between 21 and 30 feet the cost for similar improvement will be about $7,000,000 per foot.

Assuming that the Government pays 3 per cent for the money expended on improvements, and one-half of 1 per cent of cost for maintenance of improved channels, the annual increase in fixed

charges for each additional foot depth of waterways would be approximately $175,000 for channels less than 21 feet deep, and $245,000 for channels between 21 and 30 feet deep.

The actual freight carried on the lakes in 1899 was not far from 40,000,000 tons, making the average increase for the cost per ton transported, $0.0044 and $0.0061, respectively, for fixed charges due to 1 foot improvement of channels. The actual average rate per ton charged for freight passing Sault Ste. Marie in 1899 was $0.87, from which it appears that the cost of improving the harbors and channels less than 21 feet deep will increase the rate of transportation one-half of 1 per cent, and for channels between 21 and 30 feet deep, seven-tenths of 1 per cent for each foot of improvement.

Ships capable of steaming 12½ statute miles per hour in the open lake make from twenty-three to twenty-five round trips between Buffalo and Duluth during an average season of navigation, or a round trip once in ten days, three days of which are due to terminal detentions.

Referring to the cost and running expenses of type carriers best adapted to waterways of 21 and 30 feet depths, given in table on page 253, and assuming that these steamers make the same number of round trips per season in the respective waterways as the larger ships now in the service, the cost per ton-mile for transportation, not including sinking fund and profit to shipowner, would be 0.350 mills for the 21-foot channel and 0.338 mills for the 30-foot channel, from which it appears that the decrease in cost of transportation, due to increase of draft of ship, would amount to about one-third of 1 per cent of the transportation rate for each foot increase, indicating that for the type of ship considered there is no economy in improving lake channels where 21 feet deep, and that, with the depth of waterway increased to 30 feet, the interest on cost of improvement, with annual maintenance, would be at least twice the amount that would be saved to the producer by lower rates of transportation likely to result from deeper channels.

It is true that the fixed charges arising from interest on the cost of construction, with annual expense for operation and maintenance, are paid by the Government; but whether paid from Government revenues or by a toll on traffic, the net result is the same.

A draft of 19 feet is necessary for vessels best adapted for the commerce and safe navigation of the lakes, and since the free movement of ships in shallow water requires at least 2 feet of water between the keel and bottom where the shallow channel is of considerable length, it appears that 21 feet is about the least depth which can be established for the lake waterways consistent with securing a minimum rate of transportation for ships best adapted for the lake service.

The traffic capacity of the lake system of waterways is practically unlimited except at Sault Ste. Marie, where additional locks will be needed with the development of new commerce.

The present structures at Sault Ste. Marie are adapted for passing

the ships which will navigate the lakes, if the ultimate depth of harbors and waterways be fixed at 21 feet, and it is probable that, with such limit definitely fixed, the construction of ships in the future would be adapted to the conditions and their dimensions become more uniform than at present. A system of 21-foot channels can be easily completed in the near future by regulating the levels of Lake Erie and Lake St. Clair above the present mean stage and improving the St. Marys River and the entrances of lake harbors to correspond. If, however, a greater depth than 21 feet be fixed for the navigable channels the cost will be enormously increased, a long time will be consumed in executing the work, and millions of dollars' worth of vessel property will become obsolete by being forced out of business by larger freight carriers as the depths of connecting channels are gradually increased.

The one thing above all others essential for securing a fixed minimum rate of transportation on the Great Lakes is to have the final depth to be given waterways definitely fixed, and to obtain such depth at the earliest possible date.

From an engineering point of view it is also essential that final dimensions be fixed for the connecting channels of the lake waterways, for the reason that each additional foot of depth given the channel decreases the total fall between the lakes and diminishes the depth of water on the lower miter sills of the locks at Sault Ste. Marie a like amount.

If there is no economy in making the lake channels more than 21 feet deep for domestic traffic, the only legitimate reason for waterways for more than that depth between the lakes and tide water would be to allow the best types of ocean freight carriers to reach the lake ports. For this purpose it would be necessary to make only the terminal lake harbors 30 feet deep, the cost of which, with that for deepening the connecting channels from 21 to 30 feet, would probably be about $50,000,000.

A 30-foot waterway from the lakes to the Atlantic will cost approximately $100,000,000 more than a ship canal 21 feet deep, and therefore if the producers of the United States are to be benefited by such a waterway the resulting direct and indirect annual benefits must exceed the difference in the fixed charges of the two routes due to interest on cost of construction and expenditures for maintenance and operation, which will amount to about $5,000,000 a year.

The capacity of these waterways has been estimated at about 25,000,000 net tons per year, of which it is probable that less than 6,250,000 tons would be foreign commerce, from which it appears that to establish 30-foot navigation between the Atlantic and lake ports for foreign commerce will cost the Government about 80 cents for every ton of export freight transported when the canal is utilized to its full capacity.

It is true that increased transportation facilities will develop new industries and new commerce, but when we consider that it will be many years before the traffic of the waterway will reach 25,000,000 tons annually it is not reasonable to expect that the direct and indirect benefits arising from foreign trade of one-fourth this amount through a 30-foot waterway will exceed $5,000,000 the returns to be obtained with a 21-foot ship canal, even if all foreign commerce be subject to transfer delays and charges at New York.

The maximum capacity of a 30-foot waterway with single locks 740 feet long and 80 feet wide is but little greater than for a 21-foot canal with smaller locks, for the reason that the time required for passing ships through locks increases with the dimensions of lock chamber, and while a larger class of vessels would use the deeper waterway, the number which could be passed during the navigation season would be less.

If necessary to design a waterway of greater capacity than the two which have been considered, it will be far more economical to duplicate the single locks of the 21-foot canal than to increase the dimensions of canal prism to allow passage of ships of larger size.

If the locks for the 21-foot waterways should be given larger dimensions than required for the type carrier boat adopted for the channel, for the purpose of developing shipbuilding industries on the lakes, the annual traffic capacity would be decreased and the relative capacity of the two channels become more nearly proportional to the tonnage of the ships which would use them.

From a careful study of the economical and safe speeds of ships in restricted waterways it is found that the cross section of the channel should be about five and five-tenths times that of the larger ships for which designed, which ratio has been used in fixing the dimensions of the prisms of the waterways.

The dimensions of a ship canal to furnish transportation between terminals at a minimum rate must be such that the earning capacity of type carriers in time saved by greater speed in canals of larger section will be less than the amount of the interest on difference in cost and expense of maintenance, and greater for the time lost by slower speed in canals of smaller section than the amount saved in fixed charges for interest and maintenance.

For the class of vessels which may be expected to utilize waterways 21 and 30 feet deep between the lakes and tide water, the areas of the cross sections of canal prisms to fulfill the above conditions would be approximately 5,000 square feet in rock and 5,500 square feet in earth for the 21-foot channel, and 7,500 square feet in rock and 8,000 square feet in earth for the 30-foot channel.

The prism for the 21-foot channel adopted by the Board has a bottom width of 215 feet, making the area of cross section 5,497 square feet, and corresponds closely with that of the St. Clair Flats

Canal, through which there is an annual traffic of over 30,000,000 tons, transported in steamers and barges which traverse the canal with speeds ranging from 5 to 15 miles per hour. The Government regulations require that steamers shall not exceed a speed of 8 miles per hour in the canal, and from actual observation it has been found that the larger steamers, without tows, maintain speeds of from 7 to 10 miles per hour, depending upon whether running with or against the current of 1.71 miles velocity in the canal.

In view of the great number of vessels traversing the canal, its exposure to the full force of the wind from all directions, its short length, and the danger from cross currents at its terminals, it is desirable that the canal should be made at least 600 feet wide.

The canal has practically the same surface width as that adopted for the standard cross section of the 21-foot waterway, but as the canal is excavated between piers its bottom width and cross section are a little greater. The dimensions of prism for the 21-foot waterway are intended for locations where there will be no currents in the channel of sufficient velocity to materially interfere with navigation, and in rivers where such currents do exist estimates have been made for wider channels.

Referring to Tables III and V of Appendix No. 4, it will be seen that the type ships of 19 feet and 27 feet draft, capable of steaming 12½ miles per hour in the open lake, are estimated as being able to maintain 7.55 miles and 7.47 miles per hour, respectively, on tangents in waterways 21 and 30 feet deep.

These speeds are based upon the theory of retardation of ships by shallow water and restricted waterways, discussed in Appendix No. 4, and upon the actual performance of the larger ships of the lake fleet in the Great Lakes and connecting waterways.

The average round-trip time between Duluth and Buffalo of the 12½-mile steamers in the lake service corresponds almost exactly with that resulting from computing the sailing time for the same routes by Table V of Appendix No. 4.

A careful study of the performance of the vessels of the lake fleet in the St. Clair Canal indicates that, except at times of heavy winds, it can be safely navigated at a speed of at least 10 miles per hour, and therefore the speed of 7.55 miles per hour adopted for tangents on the proposed 21-foot ship canal, which would have practically the same width and depth as the St. Clair Canal, is certainly safe and practical.

The route adopted for these proposed channels through the lakes is practically the same as that now in use, except at the Limekiln Crossing of the Detroit River, and between Hay and Mud lakes, on the St. Marys River.

The Limekiln Crossing channels, as now constructed, have sharp curves and are dangerous to navigate, and should be straightened and made 600 feet wide. The estimates submitted with this report are

based on a channel 600 feet wide, constructed on a continuation across the reef of the tangent east of Bois Blanc Island, as shown on plates 12 and 13.

For the improvement of the St. Marys River the estimates are for a channel 600 feet wide through the West Neebish branch of the river, which makes the route 1.2 miles shorter than the present route and can be improved for the required dimensions of channel for less cost than on the route now used.

From an engineering point of view the change is desirable on account of the better alignment of channel which can be made and better opportunity to execute the work without interference from passing steamers.

## THE NIAGARA SHIP-CANAL ROUTES.

If, taking the cost of construction and maintenance into account, the commerce tributary to the lake system of waterways can be transported to the seaboard more economically with channels improved for a minimum depth of 21 feet than if made 30 feet deep, as has been shown to be the case in Appendix No. 5, part 2, the comparison of waterways between the lakes and the Atlantic is reduced to the consideration of the different 21-foot routes which have been investigated.

A careful reconnoissance made by the Board in advance of the field work showed that only two of the routes from Lake Erie to Lake Ontario were worthy of investigation, viz: The route from the Niagara River at Tonawanda to Lake Ontario at Olcott, and from the river at Lasalle to Lewiston and thence through the Niagara River to the lake.

These were thoroughly investigated relative to volume and kind of material to be excavated, nature and dimensions of structures which will be needed, and character of foundations on which such structures will have to be erected.

The difficulties to be overcome on the two routes are practically the same, and the real comparative merits of the waterways depend largely upon relative cost to construct and maintain them and the difference in time required by a type steamship to traverse the respective routes between points common to each.

On the Tonawanda-Olcott route several alternative lines were examined to determine the best location for locking down the escarpment near Lockport. The line down the so-called "Gulf," which has been followed in previous surveys, was found to involve the construction of a high dam and undesirable alignment of the waterway at locks and approaches, and a location was made on a tangent down the escarpment a little west of the "Gulf," by which better location and foundations can be had for lock structures at less expense for both excavation and construction.

At the Lake Ontario end of the canal an artificial harbor will have to be constructed by building breakwaters outside of the entrance and enlarging the mouth of Eighteen Mile Creek for a distance of about a

mile back from the lake, whereas on the Lasalle-Lewiston route the Niagara River constitutes one of the most capacious and safe harbors on the lake waterways.

The question has been raised as to the advisability of constructing locks, which will cost several million dollars, as close to the boundary between the United States and Canada as will be the case at the Lewiston escarpment; but when we consider the important lock and regulating structures which will be needed at the head of Niagara River, the deep channels already excavated in Canadian waters at the mouth of the Detroit River, and the locks and canals at Sault Ste Marie, it is difficult to conceive, if the Lewiston location is objectionable for military reasons, why similar reasons should not have prevented the improvement of the entire upper lake system of waterways.

The Lasalle-Lewiston route has fewer important railroad crossings than the Olcott route, and does not interfere with manufacturing and private enterprises to the extent that the latter does in the vicinity of Tonawanda.

A steamship of 19 feet draft, capable of steaming 12½ statute miles per hour in the open lake, would traverse the Lasalle-Lewiston route from the proposed Buffalo regulating works to the junction of the two routes in Lake Ontario in nine hours and fifty-eight minutes, and between the same points on the Tonawanda-Olcott route in eleven hours and six minutes—making a difference of one hour and eight minutes, or over 11 per cent of total time of passage, in favor of the Lasalle-Lewiston route.

The total estimated cost of the Tonawanda-Olcott route, including regulating works at the foot of Lake Erie, is $48,533,400, and for the Lasalle-Lewiston route, $42,472,900—making an estimated saving of $6,060,500 if the waterway should be constructed on the latter route.

From an engineering and financial point of view, and from the less danger of delays and accidents to navigation in the comparatively short reach of restricted waterway on the Lewiston line, it appears to be the preferable location on which to construct a ship canal.

### WATERWAYS FROM LAKE ONTARIO TO THE ATLANTIC.

The routes via the Oswego, Mohawk, and Hudson rivers and down the St. Lawrence River, Lake Champlain, and Hudson River were the only ones found worthy of complete surveys, plans, and estimates.

Consideration was given to lines from Big Sodus Bay and Little Sodus Bay to the Mohawk line near Oneida Lake, but preliminary estimates indicated beyond question that these routes would cost much more to construct and would take much longer for a steamer to traverse than either of the others, and were not considered further by the Board.

The conditions existing on the two routes investigated are so radically different that the comparison must depend more upon

the conclusions deduced from discussion of relative advantages in Appendix No. 5, Part 2, than upon the natural features of the sections through which the lines are located. In the project by the Oswego and Mohawk rivers it is proposed to lock up from the elevation of 245.4 feet at Oswego Harbor to 379 feet for the low-level plan, and 416 feet for the high-level system on the summit between Oneida Lake and the Mohawk river, in both of which projects the water to generate power for operating the locks and for locking ships across the divide must be secured by storage in reservoirs located on the waterway or on adjacent watersheds.

The lockage required to cross the divide with the low-level project will be 267 feet and for the high-level project 341 feet, making the route expensive to construct and slow to navigate.

The route down the St. Lawrence through Lake Champlain and the Hudson River is a down-grade canal, having a minimum amount of lockage and an ample supply of water taken directly from the St. Lawrence River, but has the disadvantage of being partly in Canadian territory and about 208 miles longer than the Oswego-Mohawk route.

The location and design of the waterway by both routes have been made with reference to interfering the least possible with manufacturing interests at water-power sites.

On the Champlain route the changes, except at Fort Miller, will be beneficial to the water-power interests, but on the Oswego and Mohawk a rearrangement of several of the power plants will be necessary. At Oswego and on the Mohawk route below Schenectady all interference of power rights has been avoided by locating the routes outside of the river valleys.

On the Oswego-Mohawk route, the low-summit-level project, utilizing Oneida Lake as a principal storage reservoir, will cost about $1,678,100 more than the high-summit-level project with water supply obtained from storage reservoirs in the valleys of the Black and Salmon rivers, but will have the advantage of not having a long feeder line to maintain, and with not interfering with water-power rights outside of the waterway location.

The only grave engineering difficulty to be overcome in connection with the low-level plan is the liability of landslides in the deep cut, which in places is through soil which unless thoroughly drained may have a tendency to slide.

A system of back drainage to prevent landslides has been provided for in the estimates, and in the opinion of the writer the low-level plan is feasible and is the preferable project to carry out in case the waterway should be constructed.

Probably the most serious difficulty to adjust on either route, if the waterway should be constructed, will be to make satisfactory arrangements for railroad crossings. This is especially the case in the

Mohawk Valley, where the river is paralleled by the four tracks of the New York Central and the two tracks of the West Shore railroads.

Ample provisions have been made in estimates for either swing or bascule bridges for all crossings, but in the case of the New York Central crossing, the number of trains is so great that a high grade crossing on a long embankment or an embankment and trestle may be necessary.

With a slight readjustment of the railroad lines in the vicinity of Rome only one such high viaduct will be needed.

The substitute location of line adopted, from Schenectady to the Hudson River below Albany, involves a deep cutting at South Schenectady, but will be in stable soil and will be safe construction.

A waterway from Schenectady to the Hudson via the Mohawk Valley, would involve sharp curves, difficult and dangerous river crossings, and with damages to water-power privileges would probably cost over $20,000,000 in excess of the line located down the Normans Kill.

From the mouth of Normans Kill to deep water in the lower Hudson the Champlain and the Oswego-Mohawk routes have a common location.

The following table gives the details of the lengths of the channels of different dimensions, and amount of lockage on the two routes between Lake Erie and New York:

BUFFALO TO NEW YORK.

| | Oswego-Mohawk route. | | Champlain route. |
|---|---|---|---|
| | High level. | Low level. | |
| Total distance ..... miles.. | 477.04 | 476.94 | 685.21 |
| Fall, regulated stage of Lake Erie to mean tide ..... feet.. | 574.5 | 574.5 | 574.5 |
| Down lockage ..... do... | 742.6 | 705.6 | 547.2 |
| Up lockage ..... do... | 170.6 | 133.6 | 0.0 |
| Total lockage ..... do... | 913.2 | 839.2 | 547.2 |
| Number of locks, including guard locks ..... | 40 | 38 | 21 |
| Number of guard locks ..... | 1 | 1 | 2 |
| Standard canal ..... miles.. | 102.56 | 102.42 | 102.35 |
| Canalized river: | | | |
| 200 to 250 feet wide ..... do... | | | 1.51 |
| 250 to 300 feet wide ..... do... | 20.38 | 20.38 | |
| 300 to 350 feet wide ..... do... | 12.37 | 12.37 | 38.97 |
| 350 to 400 feet wide ..... do... | 2.59 | 2.59 | |
| 400 to 450 feet wide ..... do... | 13.90 | 13.90 | 8.08 |
| 450 to 500 feet wide ..... do... | 8.99 | 8.99 | 11.59 |
| 500 to 1,000 feet wide ..... do... | 39.15 | 37.65 | 73.65 |
| Open lake and river ..... do... | 277.10 | 278.64 | 449.06 |
| Total ..... | 477.04 | 476.94 | 685.21 |

It will be noted that of the 574.5 feet fall from Lake Erie to tide water at time of low stage of rivers, 572 feet are overcome by locks and 2.5 feet by river slopes on the Mohawk route and 547.2 feet by locks and 27.3 feet by river slopes on the Champlain route. At times of high water in the rivers the slopes will be steeper and the total fall at locks less than at low stage.

The Champlain route is a down-grade canal from the lakes to the seaboard, and while the large amount of fall in the St. Lawrence River causes rapid currents, the maximum traffic is in the same direction, and therefore is subject to no delay from this condition.

The estimated cost of these routes from Lake Erie to the Atlantic are as follows:

| | |
|---|---|
| Champlain route | $183,420,600 |
| Oswego Mohawk route: | |
| High level | 197,718,200 |
| Low level | 199,396,300 |

A study of the length of the ice season on the lakes and connecting channels indicates that open navigation can be maintained on the Champlain route 230 days and via the Mohawk route 245 days for average years.

Referring to Table II of Appendix No. 5, Part 2, it will be noted that the round trip from New York to Chicago, including terminal detentions, will take sixteen days and nine hours for the Champlain route and fifteen days and eight hours for the Mohawk route, or, for a full navigation season, a steamship capable of steaming 12½ statute miles per hour in the open lake would be able to make fourteen and sixteen round trips in the respective waterways. That is, the ship on the Mohawk waterway would make fifteen round trips in the same time that fourteen trips on the Champlain route could be made, while the greater length of season on the Mohawk route permits still another round trip.

A steamship could therefore transport freight from Chicago to New York over the Oswego-Mohawk route for 93 per cent of the rate it would be necessary to charge on the Champlain route to make the same annual profit.

Assuming that freight can be transported over the improved waterway between New York and Chicago for an average rate of $1 per ton, the saving by using the Mohawk route, with an annual traffic of 20,000,000 tons, would amount to $1,400,000.

If the more expensive low-level Mohawk waterway should be constructed, the first cost would be about $15,975,700 in excess of what it would cost to construct the Champlain route. If 3 per cent interest be assumed as the rate paid by the Government for the money used in constructing the waterway, the saving in the annual fixed charges due to the difference in cost of the waterways would be $479,270 and for the difference in cost of operation and maintenance $642,740, making a total of $1,122,010 in favor of the Champlain route, or about 80 per cent of the amount which would be saved on transportation rates by using the Mohawk waterway. For any greater transportation rate between Chicago and New York than $1 per ton the comparative economy of the Mohawk route will be greater and for any lower rate it will be less Steamers operating solely in the lake trade and

going out of commission in the winter season would make two more round trips per year on the Mohawk waterway than could be made by the Champlain route, making the net earning capacity of steamer one-seventh greater for Mohawk route, in which case, if the volume of traffic over the proposed waterway should exceed 8,000,000 tons annually, the saving on transportation rates by using the Mohawk route would exceed the difference in fixed charges due to the less cost for construction and maintenance of the Champlain route.

The estimated cost of these routes has been based upon the same standard cross-section and unit prices for similar conditions, the speeds which can be maintained in the waterways have been deducted in a similar way for each route, and the rates of transportation between terminals determined from the sailing time of a type steamer as deduced from the actual performance of similar ships in the lakes and connecting channels.

It is therefore evident that errors which may have been introduced by erroneous assumptions will be common to both routes and will not materially affect the conclusions deduced from the comparisons.

A large portion of the commerce which will be transported in these waterways, if constructed, will be for domestic consumption, and must necessarily be delivered at the home market where needed, and as a result the volume of export commerce with lake ports will follow the same transportation lines as used for domestic trade. The choice of routes should therefore be made with reference to reaching the New York market and the ports on the Atlantic coast accessible by the steamers which will be constructed for the lake and seacoast trade.

Many of the South Atlantic ports will not admit ships of over 20 feet draft, and therefore the expenses for transfer of domestic freight, if carried in deep-draft ships, would probably be fully as large as for transfer of export traffic through the canal if transported in vessels adapted to 21-foot channels through the connecting waterways of the Great Lakes.

From a careful consideration of the type ship best adapted for carrying the lake commerce, and of the depth of channels and waterways of the lakes and from the lakes to the Atlantic required for such ships, it is evident that the proposed 21-foot waterway will furnish better returns for the transportation of domestic and foreign commerce than can be obtained by constructing a waterway 30 feet deep from the lake ports to the seaboard.

A careful comparison of the engineering difficulties to be overcome in constructing a waterway from the lakes to the Atlantic by the Oswego-Mohawk route and by the Champlain route, of the cost to construct and operate them, and of the time required for steamers adapted to the lake and coast trade to make round trips between terminals, strongly indicates that the former is the preferable route to adopt if the waterway is to be built.

The probability of extensive shipbuilding industries being developed on the Great Lakes by the construction of a deep waterway to the Atlantic may make it desirable to adopt locks 80 feet wide for passing war ships instead of 60 feet wide, as estimated in this report.

Such construction would add $4,221,000 to the estimated cost of the Mohawk route and $2,560,000 to that of the Champlain route.

The annual capacity of each route would be diminished by the additional time required for filling and emptying locks and the time for round trips correspondingly increased, but as these changes would apply to both routes the relative comparison of the two waterways would not be materially changed. The changes would, however, make the comparison between the 21 and 30 foot waterways less favorable to the former.

Respectfully submitted.

GEO. Y. WISNER.

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

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APPENDIX NO. 5.—PART 2.

## RELATIVE ADVANTAGES OF THE 21 AND 30 FOOT WATERWAYS.

The sundry civil act of July 1, 1898, definitely fixes the depths of the waterways to be investigated by the Board at 21 and 30 feet respectively, and requires a statement of the relative advantages thereof. The following investigation has been made to determine, as far as may be found possible, the relative advantages of the two waterways.

These advantages may be either direct or indirect. The direct advantages consist of the relative returns in value received for the expenditures incurred in the construction, maintenance, and operation of the two waterways respectively. The indirect advantages arise from the influence of the waterways upon the commerce of the country.

### RELATIVE DIRECT ADVANTAGES.

In order to investigate the relative direct advantages of the waterways, it is desirable, for the sake of clearness, to state in a condensed form certain general considerations which relate to all lines of transportation.

When an article of merchandise is transported from one point to another, its least value at the point of delivery must be the sum of its value at the shipping point plus the cost of transportation; otherwise the transport would not generally be effected. If $v$ represents the difference in the value of the freight unit at the terminals, Q the total number of freight units transported in a given period (say, one year), and K the total cost of transportation in the same period,

$U = Qv - K$ may be taken as an approximate measure of the direct utility of the transportation line.

The cost of transportation (K) is composed of two parts, (1) the toll or charge for the use of the line, and (2) the transport proper or charge for carrying the freight over the line. It is necessary to distinguish between these two charges since they are often paid to different parties.

The toll consists of the annual interest on the cost of constructing the line and the annual cost of its maintenance, operation, and superintendence. This charge is paid by the users to the proprietor of the line.

The transport proper consists of the annual interest on the cost of carriages, the annual cost of their maintenance, depreciation, and operation, and such terminal and other charges as may attach to the traffic. These charges are paid by the users to the carrier.

If T represents the toll and P represents the transport proper, the equation of utility becomes

$$U = Qv - T - P \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

In this equation U represents the amount of benefit which should be annually divided between the parties interested in the traffic after the payment of toll and transportation charges. It is, however, in some cases only an approximate measure of utility, for it is based on the single consideration of the difference between terminal value and cost of transportation. There are, however, other important elements involved in the determination of the measure of utility. The speed and regularity with which the transport is effected are often important elements of value, and the capacity of the line for transportation may limit the volume and cost of the traffic.

If $I_w$ represents the annual interest on the cost of constructing the line; $M_w$ the annual cost of its maintenance and operation; $I_m$ the annual interest on the cost of carriages, and $M_m$ the annual cost of maintenance, depreciation, and operation of carriages, including all charges connected with moving the traffic, we have—

$$T = I_w + M_w$$

and—

$$P = I_m + M_m$$

and—

$$U = Qv - I_w - M_w - I_m - M_m \quad . \quad . \quad . \quad . \quad . \quad (2)$$

It will be observed that, in the general case, there are three parties interested in the transport movement—the carrier, the proprietor of the line, and the shipper and receiver using the line. When these parties are independent their interests conflict and each will endeavor to get as large a part of $Qv$ as possible.

The carrier must receive $M_m$, otherwise the freight will not be moved. He must also receive a fair value of $I_m$, for although he

might move the freight for a while without receiving any interest on the cost of his carriages, he would refuse to invest money in new carriages to replace those which were worn out and the traffic would soon cease.

The proprietor must receive $M_w$, otherwise he will cease maintaining and operating the line. He need not, however, receive a fair value of $I_w$, for having invested his money in the line, he can not remove it, and it will pay him to maintain and operate the line as long as he receives $M_w$ and a very small value for $I_w$. Indeed, he may continue the operation of the line without receiving any value for $I_w$, in the hope of future gains under more favorable traffic conditions.

The users or general public will employ the line if they receive a very small value for U, so that it is to the interest of the carrier and proprietor to make U as small as possible by making the freight charges as heavy as the traffic will bear. But the total amount received depends upon the volume of traffic Q, and this may often be increased by diminishing the transportation charges. It is, therefore, not always to the advantage of the proprietor and carrier to impose high charges upon the traffic.

This distinction between toll and transport proper exists in all cases, although it is not easy to separate the two charges where the proprietor and carrier are one and the same party, as in the case of a railroad. In such a case the toll is simply the difference between the total cost of transportation and the cost of moving the freight over the line.

When the three parties interested in the traffic movement are independent of each other, it is evident that after each has received a reasonable portion of the proceeds derived from the traffic, the remaining part of U should be divided between them. The proprietor is generally a company, the shares of which are held by many persons, and the carrier often represents a large number of owners. These parties are as much entitled as the users to a share in the extra earnings of the line. In dividing these extra earnings the risk of loss assumed by each party should be taken into consideration. Thus, as has been before remarked, the proprietor can not withdraw his money from the line even if the traffic fails to pay him any returns for his investment. He should therefore receive the largest proportional share of the extra earnings. The carrier should receive the next largest proportional share, for he risks the interest upon the value of his plant and the cost of operating it, which may turn out to be greater than the amount received for transportation. So long as the charge for transport proper does not fluctuate, the user runs no risk from the use of the line and therefore should receive the smallest proportional part of the extra earnings.

When the Government is the proprietor of the line, the user (or general public), the proprietor, and the carrier become one and the

same party so far as the cost of construction, operation, and maintenance of the line is concerned, and if the charges for transport proper can be restricted within reasonable limits the toll may be abolished as a direct charge upon the traffic, since it will be recovered by the people in the increased value of U. Moreover, as will be explained hereafter, the indirect benefits expected from the establishment of the line may fully justify the assumption of the toll by the Government. In the case of a line where the carrying business is a monopoly (such as a railroad), the tendency would be for the carrier to take as much as possible of the benefit resulting from the abolition of the toll. In the case of a line open to the competition of all carriers (like a great national waterway), the law that where there is free competition the charges for transportation must closely approximate the net cost will operate. This is one reason why it may sometimes be an economical advantage for the Government to assume the cost of construction, maintenance, and operation of a waterway, while it would not generally be an advantage to the public in the case of a railroad unless the Government also conducted the business of carrier.

The special problem which we are required to consider consists in the determination of the relative advantages of two lines of water transportation of different depths extending from Lake Superior and Lake Michigan to the Atlantic tide waters. The line adopted will compete with the railroads for freight transportation over a large part of the distance. Where the cost of transportation is relatively large, in comparison with the value of the transported commodity at the starting point, speed will generally be of less value than cost of transport, and the traffic will generally be by the cheaper line without regard to time. If the Government assumes the toll, as is proposed in the cases considered, the cost of transportation will be much less over the waterway than over the railroad, but the railroad will generally have the advantage of speed. Hence we may make the following assumptions:

1. The toll on the waterway is to be assumed by the Government.

2. The traffic will consist of the movement of bulky freight, the cost of the transportation of which is relatively large in comparison with its value at the starting point. In the comparisons to be made it will be unnecessary to consider speed as a direct element of value. Indirectly, however, it is an element of importance in the determination of the unit cost of transportation.

For this case equation (1) becomes

$$U = Qv - P \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If U′, Q′, and P′ represent the values of U, Q, and P for a second waterway, we have

$$U' = Q'v - P' \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

If $p$ and $p'$ represent the average cost of moving the freight unit over the two lines respectively, we have

$$P = Qp \text{ and } P' = Q'p'$$

and

$$U = Q(r-p),\ U' = Q'(r-p')$$

and

$$\frac{U'}{U} = \frac{Q'}{Q}\,\frac{r-p'}{r-p} \quad \ldots\ldots\ldots \quad (5)$$

U and U′ are the annual values returned to the people in compensation for the assumption of the toll by the Government. If C and C′ represent the cost of construction of the two waterways respectively and R and R′ the annual returns upon $100 expended in construction, after the payment of the costs of maintenance, operation, and transport proper, in the two cases compared, we obtain

$$U = \frac{CR}{100} + M_w$$

and

$$U' = \frac{C'R'}{100} + M'_w$$

The values of R and R′ are measures of the relative direct benefits derived by the public in the two cases. Substituting these values in equation 5, we obtain

$$R' = \frac{Q'C}{QC'}\left(\frac{r-p'}{r-p}\right)R + \frac{100}{C'}\,\frac{Q'}{Q}\left(\frac{r-p'}{r-p}\right)M_w - \frac{100}{C'}M'_w \quad (6)^*$$

By substituting the values of U and P in equation 3 we obtain

$$R = \frac{100}{C}[Q(v-p) - M_w] \quad \ldots\ldots \quad (7)$$

If $R_r = \frac{R'}{R}$, equation 6 may be written

$$R_r = \frac{Q'}{Q}\left(\frac{r-p'}{r-p}\right)\left(\frac{C}{C'} + \frac{100}{C'}\,\frac{M_w}{R}\right) - \frac{100}{C'}\,\frac{M'_w}{R} \quad \ldots \quad (8)$$

THE WATERWAYS.

The waterways to be compared will be about equally well adapted to navigation by small vessels engaged in way traffic. The determi-

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*The value of R may also be placed under the following form:

$$R' = \frac{Q}{C}\,\frac{C'}{Q}R - \frac{100}{C'}\left(\frac{Q}{Q}M_w - M_w\right) + \frac{100}{C}Q(p-p')$$

This form exhibits very clearly the influence of the various elements of the problem upon the value of R′. Thus the first term of the second member depends principally upon the traffic capacities of the waterways per unit cost of construction, the second term upon costs of maintenance, and the third term upon costs of transport proper. It is not so well adapted to numerical discussion as equation 8, since it requires the assumption of a separate value of Q in the third term for each waterway.

nation of relative direct benefit will therefore be limited to the consideration of through traffic conducted in the most economical carriers.

The waterways have two main branches of through traffic extending from the head of Lake Superior and the head of Lake Michigan to New York. These will be considered separately and their terminals will be assumed to be at Duluth and New York and at Chicago and New York, respectively. The ocean line may be left out of consideration in the comparison, since the same class of carriers is assumed to affect the transport over it in all cases. Part of the traffic will be to domestic markets, some of which will be at the coast ports, and part of it will be to foreign markets. For each line the comparison will therefore be made for two separate cases, viz, (1) for domestic markets and (2) for foreign markets.

The investigations of the Board show that for both waterways the most favorable route from Lake Erie to Lake Ontario is via Lasalle, Lewiston, and the Niagara River. This route is therefore adopted as part of every line investigated.

The routes from Duluth and Chicago to New York, which will be compared, are as follows:

1. Thirty-foot waterway via Lasalle, Lewiston, St. Lawrence River, and Lake Champlain.
2. Thirty-foot waterway via Lasalle, Lewiston, and the Mohawk Valley, high-level plan.
3. Thirty-foot waterway via Lasalle, Lewiston, and the Mohawk Valley, low-level plan.
4. Twenty-one foot waterway via Lasalle, Lewiston, St. Lawrence River, and Lake Champlain.
5. Twenty-one foot waterway via Lasalle, Lewiston, and the Mohawk Valley, high-level plan.
6. Twenty-one foot waterway via Lasalle, Lewiston, and the Mohawk Valley, low-level plan.

### THE TYPE CARRIERS.

The characteristic feature of the waterway having a depth of 21 feet is that it can be navigated by lake vessels, so that freight does not have to be transferred to other carriers in passing from lake to canal or from canal to lake. The depth, however, will not be sufficient for navigation by vessels of the most economical type to cross the ocean, and it is therefore assumed that freight destined for ports beyond sea will have to be transferred to other carriers at the seaboard. For reasons which will be given elsewhere, it is assumed that the type carrier adopted for this waterway will be adapted not only to lake and canal traffic, but also to economical navigation along the coasts of North and South America.

The characteristic feature of the waterway having a depth of 30 feet is that it can be navigated by both lake and ocean-crossing vessels, and so transference of freight will not be required.

The traffic on either waterway will consist principally of the move-

ment of bulky freight, such as grain, coal, lumber, and ores, to domestic and coast markets or to markets beyond the sea. Probably this freight will be carried for a time in a great variety of vessels, but there will be a gradual tendency to develop a type of vessel adapted to the most economical service in connection with the waterway considered. It is, of course, impossible to predict with certainty what these types will be for the waterways in question, but for the purposes of this investigation type carriers have been selected which, it is believed, will transport freight at the lowest cost.

The following table gives data for various carriers and the cost of transportation per ton-mile in open water computed therefrom. This cost is determined by dividing the daily cost of the vessel, including interest, depreciation, repairs, and insurance, by the product of the number of tons in the full cargo and the number of miles traveled in twenty-four hours in open sea. It takes no account of detentions, profits, shore expenses, or final absorption of the capital invested, and therefore should not be confounded with the actual cost of transportation. It is employed only to determine the relative economy of transportation of the different vessels in open water.

The table includes vessels of 19, 23, and 27 feet draft, lengths from 480 to 550 feet, breadths from 52 to 60 feet, and speeds of 12½ and 15 statute miles per hour in open water. These data have been prepared for the Board by Mr. Frank E. Kirby, the eminent marine engineer, and therefore may be accepted with great confidence. The carriers are modern steel vessels with water ballast when light. Nos. 1 to 8 are single-screw steamers, and Nos. 9 to 14 are twin screws.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of carrier | 1 | 3 | 5 | 7 | 9 | 11 | 13 |
| Length over all, feet | 480 | 480 | 480 | 500 | 520 | 540 | 550 |
| Breadth, do | 52 | 52 | 52 | 54 | 56 | 58 | 60 |
| Draft, do | 19 | 23 | 27 | 27 | 27 | 27 | 27 |
| Speed, statute miles per hour | 12½ | 12½ | 12½ | 12½ | 12½ | 12½ | 12½ |
| Indicated horsepower | 2,200 | 2,480 | 2,800 | 2,930 | 3,100 | 3,200 | 3,330 |
| Coal consumed per hour, pounds | 3,850 | 4,340 | 4,900 | 5,120 | 5,450 | 5,600 | 5,830 |
| Carrying capacity, net tons | 8,600 | 9,600 | 11,760 | 12,600 | 13,300 | 13,980 | 14,100 |
| Cost of ship for lake business only, dollars | 360,000 | 420,000 | 504,000 | 558,000 | 657,600 | 710,050 | 750,000 |
| Cost of ship for ocean and lake business, dollars | 387,000 | 462,000 | 554,400 | 612,400 | 705,600 | 771,400 | 828,400 |
| Pay roll per day, including subsistence, dollars | 60 | 60 | 62 | 62 | 80 | 80 | 82 |
| Percentage of cost for repairs and depreciation | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Percentage of cost for insurance | 4½ | 4½ | 4½ | 4½ | 4½ | 4½ | 4½ |
| Incidental expenses per day (coal, waste, etc.), dollars | 117 | 129 | 143 | 149 | 155 | 159 | 165 |
| Cost of transport in open water per ton-mile (ocean and lake carrier), mills | 0.128 | 0.129 | 0.121 | 0.120 | 0.129 | 0.130 | 0.136 |
| Number of carrier | 2 | 4 | 6 | 8 | 10 | 12 | 14 |
| Speed, statute miles per hour | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Indicated horsepower | 3,650 | 4,150 | 4,700 | 4,850 | 5,200 | 5,300 | 5,500 |
| Coal consumed per hour, pounds | 6,400 | 7,230 | 8,230 | 8,500 | 9,100 | 9,300 | 9,700 |
| Carrying capacity, net tons | 7,650 | 8,800 | 9,600 | 10,000 | 10,800 | 11,600 | 12,000 |
| Cost of ship for ocean and lake business, dollars | 410,000 | 507,200 | 595,000 | 661,200 | 760,000 | 836,000 | 885,000 |
| Pay roll per day, including subsistence, dollars | 72 | 74 | 76 | 76 | 96 | 98 | 102 |
| Percentage of cost for repairs and depreciation | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Percentage of cost for insurance | 4½ | 4½ | 4½ | 4½ | 4½ | 4½ | 4½ |
| Incidental expenses per day (coal, waste, etc.), dollars | 154 | 174 | 198 | 204 | 218 | 224 | 232 |
| Cost of transport in open water per ton-mile, mills | 0.141 | 0.142 | 0.148 | 0.151 | 0.158 | 0.157 | 0.159 |

The carriers which can navigate the 21-foot waterway are Nos. 1 and 2. They have a draft of 19 feet, a breadth of 52 feet, and a length of 480 feet. These dimensions are adopted for the 21-foot waterway in this investigation because they are believed to conform to the best present lake practice. The vessels are not quite as long as the longest vessels employed with the same draft, but they have nearly the greatest beam yet adopted. The cost of transport per ton-mile in open water is much greater for carrier No. 2, which has a speed of 15 statute miles per hour, than for carrier No. 1, which has a speed of 12½ miles per hour, and the difference will be increased in a restricted channel. No. 1 is therefore adopted as the type carrier for the 21-foot waterway.

All the carriers can navigate the 30-foot waterway. It appears from the costs per ton-mile given in the table that the carriers having a speed of 12½ miles per hour are much more economical than those having a speed of 15 miles per hour. Of these carriers, No. 7 is the most economical in open water, and also the most economical in a restricted channel as compared with the other carriers having a draft of 27 feet. The diminution of speed in a restricted channel varies considerably for vessels of different draft. To determine whether No. 7 is more economical than No. 1 for navigation in the 30-foot waterway, the loss of speed due to channel restriction and the resulting costs of transport per ton-mile have been calculated for the two cases. For carrier No. 1 the cost of transport per ton-mile in the 30-foot waterway is 0.308 mill, and for carrier No. 7, 0.300 mill. Carrier No. 7 is the more economical under the assumed conditions, and is therefore adopted as the type carrier for the 30-foot waterway.

### THE DATA FOR COMPARISON.

In order to apply equation 8 to the determination of the relative direct benefits to be derived from the waterways under consideration, values for the constants entering the equation must be computed or assumed. The methods employed in determining these values will now be described.

The 30-foot waterways will first be compared with each other, waterway No. 3 being taken as the standard. The 21-foot waterways will then be compared with each other, waterway No. 6 being taken as the standard. The best 30-foot waterway will then be compared with a 21-foot waterway, the latter being taken as the standard.

In equation 8, Q, C, $M_w$, R, and $p$ relate to the standard waterway and Q′, C′, $M'_w$, and $p'$ to the waterway compared therewith. In the tables the primes are omitted, except where the data refer to both waterways. For convenience the notation employed is here repeated:

C = cost of the construction of the waterway.

$M_w$ = annual cost of the maintenance and operation of the waterway.

Q = number of net tons of freight annually transported over the waterway.

$p$ = average cost of moving one ton from one terminal to the other.
$r$ = average difference in value of freight unit at terminals.
R = annual return upon $100 expended in construction of standard waterway.
R′ = annual return upon $100 expended in construction of waterway compared.

$$R, \frac{R'}{R}.$$

*1. Constants of the waterway.*—The cost of constructing each waterway (C) is obtained from the detailed estimates made by the Board. In connection with the 30-foot waterways it will be necessary to increase the depth of the harbors at Duluth and Chicago to 30 feet to afford necessary terminal facilities. The cost of deepening Duluth Harbor to 30 feet, not including maintenance, is estimated by Maj. C. B. Sears, Corps of Engineers, at $4,607,500, and the cost of establishing the same depth in Chicago Harbor is estimated by Maj. J. H. Willard, Corps of Engineers, at $5,000,000. For the 30-foot waterways these items are added to the estimates of the Board.

Major Sears estimates the cost of new piers and the protection of old ones at Duluth at $1,000,000. This has not been included in the estimate for harbor improvement, as it is assumed that the work would not be done at the expense of the Government. The estimate for Chicago Harbor does not include the cost of acquiring property nor the protection of existing structures, which, Major Willard says would be enormous.

The annual cost of maintenance and operation of each waterway ($M_w$) has been determined by the Board after a thorough study of the conditions in each case and the results of experience on existing waterways, the estimates being based upon the following assumptions:

For annual repair and maintenance of all structures, such as locks, dams, and bridges, 1 per cent upon the first cost.

For annual repair and maintenance of the canal prism, one-half of 1 per cent upon the first cost.

For annual operation of single lift, single lock, $24,740.

For annual operation of double locks, $19,358 to $38,645 per lift, depending upon the number of lifts combined.

These estimates include the estimated cost of the general supervision of the whole line.

*2. Constants of traffic volume.*—The values of Q and Q′ can not be estimated with certainty, but for the purpose of comparing waterways of the same depth and navigated by the same type carrier, it may be assumed that these quantities are proportional to the length of the average season of navigation.

In determining the round-trip load, it is assumed that the vessel will carry its full load in its eastward trip and only one-third of its load on its westward trip. As will be shown hereafter, the volume of

the westward traffic is about one-third that of the eastward traffic at the present time.

The number of days in the average season of navigation has been determined by the Board from the records of the St. Marys Falls and St. Lawrence canals for recent years.

*3. Constants of transport.*—The average cost of moving the freight unit from one terminal to the other ($p$) is computed by dividing the cost of maintaining and operating the type carrier (including interest on first cost) during the round trip by the number of tons in the round-trip load. The cost of maintenance and operation during the round trip is determined by multiplying the daily cost of carrier by the number of days in the round trip and subtracting from the result the estimated value of the coal saved during detention. On each day of detention it is assumed that 20 tons of coal are consumed, which is valued at $2 per ton.

The value of $p$ thus determined is not the freight rate. It does not include the cost of loading and unloading at the terminals, the insurance of the freight during transit, nor the shore expenses. These elements are omitted because they are assumed to be equal increments of $v$, $p$, and $p'$, and, therefore, do not affect the value of the coefficient of transport, $\frac{v-p'}{v-p}$. In the case of carrier No. 1, however, 25 cents is added to the value of $p$ for foreign traffic, this being the estimated average cost of transferring the freight unit to a deep-sea carrier.

To determine the value of the coefficient of transport $\frac{v-p'}{v-p}$ it is necessary to assume a value for $v$. The minimum value of $v$ is the actual price paid for moving the freight unit from one terminal to the other, plus the cost of transferring it to a deep-sea carrier. In 1898 the freight rate on a ton of wheat from Chicago to New York (by lake and canal, including transfer) was $1.61, and from Duluth to New York, $1.77. To these must be added $0.25 for transfer to the deep-sea carrier. The minimum value of $v$ for routes from Chicago to New York is therefore assumed to be $1.86, and for routes from Duluth to New York at $2.02. The maximum value of $v$ can not be determined; but as $v$ increases the coefficient of transport rapidly approaches a limit at which it becomes sensibly equal to unity, and the terms in equation 8 containing R become insignificant. The values of $R_1$, corresponding to extreme values of $v$, may therefore be obtained from equation 8, with the minimum values of $v$ above given and from the equation $R_1 = \frac{Q'}{Q} \cdot \frac{C}{C'}$. In the comparisons given hereafter the minimum values of $v$ are employed, because the values of $p$ and $p'$ are minimum values, and because it is desirable to give the cost of transport its full

effect in the formula. The possible variation in the value of $R_1$, due to a change in the assumed value of $c$, may be readily computed from the data given in the tables. It will be found that the possible change in $R_1$ is in every case very small, being generally in the third decimal place.

It is evident that the coefficient of transport $\frac{c-p'}{r-p}$ measures the relative benefit derived from the line per unit of freight transported, leaving out of consideration costs of construction and maintenance.

*4. Constant of return for the standard waterway.*—Changes in the value of R will produce little effect upon the value of $R_1$, determined from equation 8. It will be seen from equation 7 that R depends upon the annual volume of traffic actually moved over the standard waterway. Assuming Q = 25,000,000 tons (which is the value assumed by the Board for the discussion of technical questions affecting the waterway), values of R for foreign and domestic traffic may be computed from equation 7.

Equation 8 is applicable to any part of the traffic (foreign or domestic) if we assume that it is in the same relative proportion to the total traffic in the cases compared.

The values of the constants as computed by the methods above described, and the principal data upon which they are based are given in the following tables:

TABLE I.—*Thirty-foot waterways.*

[Type vessel No. 7.]

| No. of waterway | | No. 1. | | No. 2. | | No. 3. | |
|---|---|---|---|---|---|---|---|
| Route | | Champlain. | | Mohawk, high level | | Mohawk, low level. | |
| Terminals | | Duluth–New York. | Chicago–New York. | Duluth–New York. | Chicago–New York. | Duluth New York. | Chicago–New York. |
| Distance | statute miles. | 1,674.7 | 1,575.8 | 1,466.5 | 1,367.6 | 1,466.4 | 1,367.5 |
| Average season of navigation | days | 230.00 | 230.00 | 245.00 | 245.00 | 245.00 | 245.00 |
| Sailing time, round trip | do | 13.63 | 12.63 | 12.83 | 11.83 | 12.13 | 11.70 |
| Terminal detention, domestic | do | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Terminal detention, foreign | do | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 | 3.00 |
| Total time, round trip, domestic | do | 18.63 | 17.63 | 17.83 | 16.83 | 17.13 | 16.70 |
| Total time, round trip, foreign | do | 16.63 | 15.63 | 15.83 | 14.83 | 15.13 | 14.70 |
| Load per round trip | tons | 16,800 | 16,800 | 16,800 | 16,800 | 16,800 | 16,800 |
| Cost of waterway (including terminal harbor), (C) | dollars | 324,706,000 | 307,785,000 | 317,836,000 | 300,915,000 | 321,892,000 | 304,971,000 |
| Annual cost of maintenance and operation (Mw) | do | 2,269,794 | 2,139,903 | 2,930,308 | 2,800,417 | 2,883,158 | 2,753,267 |
| Daily cost of carrier | do | 454 | 454 | 454 | 454 | 454 | 454 |
| Difference in terminal value of freight unit (r) | do | 2.02 | 1.86 | 2.02 | 1.86 | 2.02 | 1.86 |
| Cost of moving freight unit, domestic (*p*) | do | 0.479 | 0.452 | 0.457 | 0.430 | 0.438 | 0.427 |
| Cost of moving freight unit, foreign (*p*) | do | 0.435 | 0.408 | 0.413 | 0.386 | 0.394 | 0.382 |
| $\frac{v-p'}{v-p}$, domestic | do | 0.984 | 0.983 | 0.998 | 0.998 | 1.000 | 1.000 |
| $\frac{v-p'}{v-p}$, foreign | do | 0.984 | 0.982 | 0.998 | 0.997 | 1.000 | 1.000 |
| $\frac{Q'}{Q}$ | do | 0.939 | 0.939 | 1.000 | 1.000 | 1.000 | 1.000 |
| $\frac{C}{C'}$ | do | 0.991 | 0.991 | 1.013 | 1.014 | 1.000 | 1.000 |
| $\frac{100}{C}$ | do | 0.000000308 | 0.000000325 | 0.000000315 | 0.000000332 | 0.000000311 | 0.000000328 |
| R, domestic | do | | | | | 11.28 | 10.85 |
| R, foreign | do | | | | | 11.63 | 11.22 |

TABLE II.—*Twenty-one-foot waterways.*

[Type vessel No. 1.]

| No. of waterway | | No. 4. | | No. 5. | | No. 6. | |
|---|---|---|---|---|---|---|---|
| Route | | Champlain. | | Mohawk, high level. | | Mohawk, low level. | |
| Terminals | | Duluth New York. | Chicago New York. | Duluth New York. | Chicago New York. | Duluth New York. | Chicago New York. |
| Distance | statute miles | 1,674.7 | 1,575.8 | 1,466.5 | 1,367.6 | 1,466.4 | 1,367.5 |
| Average season of navigation | days | 230.00 | 230.00 | 245.00 | 245.00 | 245.00 | 245.00 |
| Sailing time, round trip | do | 13.33 | 12.38 | 12.42 | 11.45 | 12.33 | 11.33 |
| Terminal detention, domestic | do | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| Terminal detention, foreign | do | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 | 4.00 |
| Total time, round trip, domestic | do | 17.33 | 16.38 | 16.42 | 15.45 | 16.33 | 15.33 |
| Total time, round trip, foreign | do | 17.33 | 16.38 | 16.42 | 15.45 | 16.33 | 15.33 |
| Load per round trip | tons | 11,500 | 11,500 | 11,500 | 11,500 | 11,500 | 11,500 |
| Cost of waterway (C) | dollars | 190,382,000 | 184,887,000 | 204,690,000 | 199,184,000 | 206,358,000 | 200,862,000 |
| Annual cost of maintenance and operation (Mw) | do | 1,643,445 | 1,568,266 | 2,343,478 | 2,268,299 | 2,286,189 | 2,211,010 |
| Daily cost of carrier | do | 331 | 331 | 331 | 331 | 331 | 331 |
| Difference in terminal value of freight unit ($v$) | do | 2.02 | 1.86 | 2.02 | 1.86 | 2.02 | 1.86 |
| Cost of moving freight unit, domestic ($p$) | do | 0.481 | 0.453 | 0.454 | 0.426 | 0.452 | 0.423 |
| Cost of moving freight unit, foreign ($p$) | do | 0.731 | 0.703 | 0.704 | 0.676 | 0.702 | 0.673 |
| $\frac{v-p'}{v-p}$, domestic | do | 0.982 | 0.979 | 0.999 | 0.998 | 1.000 | 1.000 |
| $\frac{v-p'}{v-p}$, foreign | do | 0.978 | 0.975 | 0.998 | 0.997 | 1.000 | 1.000 |
| $\frac{Q'}{Q}$ | do | 0.939 | 0.939 | 1.000 | 1.000 | 1.000 | 1.000 |
| $\frac{C}{C'}$ | do | 1.084 | 1.086 | 1.008 | 1.008 | 1.000 | 1.000 |
| $\frac{100}{C}$ | do | 0.0000000525 | 0.0000000541 | 0.0000000488 | 0.0000000502 | 0.0000000484 | 0.0000000498 |
| R, domestic | do | | | | | 71.87 | 16.79 |
| R, foreign | do | | | | | 14.84 | 13.68 |

## COMPARISON OF THE WATERWAYS.

*1. Thirty-foot waterways.*—The values of $R_r$ obtained from equation 8, using the data from Table I, are given in the following table, waterway No. 3 being the standard for comparison:

| No. | Route. | New York to— | Domestic. | | Foreign. | |
|---|---|---|---|---|---|---|
| | | | $R_r$. | Mean | $R_r$. | Mean. |
| 1 | Champlain | Duluth | 0.926 | 0.927 | 0.926 | 0.926 |
| | | Chicago | 0.927 | | 0.925 | |
| 2 | Mohawk high level | Duluth | 1.009 | 1.010 | 1.010 | 1.010 |
| | | Chicago | 1.010 | | 1.009 | |
| 3 | Mohawk low level (standard) | Duluth | ..... | 1.000 | ..... | 1.000 |
| | | Chicago | ..... | | | |

If the assumptions upon which this investigation is based are accepted, the above values show that the return of direct benefit from the 30-foot waterway via the St. Lawrence River and Lake Champlain (No. 1) is less for both foreign and domestic traffic than the return from either of the Mohawk Valley routes. The two Mohawk Valley waterways give practically the same returns. The difference between the Champlain and Mohawk Valley routes seems too great to be accidental. It corresponds to a change of about 11 per cent in the relative cost of construction.

*2. Twenty-one-foot waterways.*—The values of $R_r$ obtained from equation 8, using the data from Table II, are given in the following table, waterway No. 6 being the standard for comparison:

| No. | Route. | New York to— | Domestic. | | Foreign. | |
|---|---|---|---|---|---|---|
| | | | $R_r$. | Mean. | $R_r$. | Mean. |
| 4 | Champlain | Duluth | 1.013 | 1.013 | 1.012 | 1.012 |
| | | Chicago | 1.013 | | 1.012 | |
| 5 | Mohawk high level | Duluth | 1.005 | 1.005 | 1.004 | 1.003 |
| | | Chicago | 1.004 | | 1.003 | |
| 6 | Mohawk low level (standard) | Duluth | ..... | 1.000 | ..... | 1.000 |
| | | Chicago | ..... | | | |

The above values show that the return of direct benefit from the 21-foot waterway via the St. Lawrence River and Lake Champlain (No. 4) is theoretically a little greater than the return from either of the Mohawk Valley routes. The Mohawk Valley routes give nearly equal returns. Practically, however, the three routes give the same return of direct benefit, the difference between the Champlain and Mohawk routes corresponding to a change of about 1 per cent in the relative cost of construction.

*3. Twenty-one and 30 foot waterways.*—The value of $R_r$ as determined from equation 8 depends largely upon the value of $\frac{Q'}{Q}$, that is upon the relative volumes of traffic upon the waterways compared. In the preceding comparisons there was no difficulty in making a

reasonable estimate of this quantity, since the waterways considered were of the same dimensions and the traffic was assumed to be conducted in the same type carriers.

For the purpose of comparing a 30-foot waterway navigated by carrier No. 7 with a 21-foot waterway navigated by carrier No. 1 it is necessary to determine a reasonable value for this quantity. In the paper on *Locks* (Appendix No. 1) it is shown that the practical maximum annual traffic capacity of the waterway is limited by the rate at which vessels can pass through the locks. With a single lock of 20-foot lift, the maximum annual traffic capacity of the 21-foot waterway (Q) will be 25,150,000 net tons, and the maximum annual traffic capacity of the 30-foot waterway (Q′) will be 26,359,000 net tons. For this case we have $\frac{Q'}{Q} = 1.048$.

Assuming waterway No. 6 as the standard and comparing therewith waterway No. 2 (which is the best 30-foot waterway), we obtain the values of R, given in the following table:

| Waterway. | Route. | New York to— | Domestic. | | Foreign. | |
|---|---|---|---|---|---|---|
| | | | R. | Mean. | R. | Mean. |
| No. 2 (30-foot) | Mohawk high level | Duluth | 0.669 | 0.678 | 0.829 | 0.850 |
| | | Chicago | 0.687 | | 0.871 | |
| No. 6 (21-foot) | Mohawk low level (standard). | Duluth | | 1.000 | | 1.000 |
| | | Chicago | | | | |

If we suppose the single-lift locks to be duplicated, the traffic capacity of the waterway will be determined by the lockage capacity of the Lewiston flight, and we have $Q^1 = 34,405,000$, $Q = 35,801,000$, and $\frac{Q'}{Q} = 0.961$. In this case the traffic capacity of the larger waterway is actually less than that of the smaller one. The corresponding values of R, (neglecting changes in relative cost and maintenance due to the additional locks) are given in the following table:

| Waterway. | Route. | New York to— | Domestic. | | Foreign. | |
|---|---|---|---|---|---|---|
| | | | R. | Mean. | R. | Mean. |
| No. 2 (30-foot) | Mohawk high level | Duluth | 0.613 | 0.621 | 0.757 | 0.775 |
| | | Chicago | 0.629 | | 0.793 | |
| No. 6 (21-foot) | Mohawk low level (standard). | Duluth | | 1.000 | | 1.000 |
| | | Chicago | | | | |

The above values show that the return of direct benefit from the 21-foot waterway is much greater than the return from the 30-foot waterway.

It should be remarked, however, that the lock dimensions adopted by the Board for the 30-foot waterway are too large for the most economical results from a purely freight traffic, these dimensions having been chosen to provide for the passage of ships of war and large ocean

vessels built on the lakes. With locks designed for the most economical freight traffic only, somewhat better results would be obtained.

### RELATIVE INDIRECT ADVANTAGES.

The preceding discussion has been confined to the investigation of the comparative direct value of the waterways considered simply as instruments of commerce for the economical transportation of bulky low-priced freight. From this restricted point of view it appears that the 21-foot waterway is much superior to the 30-foot waterway. This is the view which would necessarily be taken by a private proprietor looking only to the direct gains which might be derived from the traffic. But when the Government is the proprietor, the problem can not be limited to such narrow conditions. The indirect benefits derived from the establishment of the line may be of such importance in their influence upon production, commerce, and the general prosperity of the people that the question of a greater or less return of direct value may become comparatively insignificant. It is of vital importance to the private proprietor that he should obtain a reasonable money return for his investment; but the Government may often wisely expend large sums for the production of general results, even when no direct return of value can be expected.

In forming an estimate of the relative indirect advantages and disadvantages of the waterways, questions must be considered which can not be stated in mathematical formulas. For a clear understanding of these questions it will be necessary to consider briefly the amount and character of the existing lake traffic and its past and probable future development, to point out the distinguishing peculiarities of transportation lines of different character and capacity, and to indicate the objects which the proposed waterways are intended to subserve.

### THE LAKE TRAFFIC.

The demand for increased facilities and diminished rates of transportation from the region of the Great Lakes to the interior of the country and to the sea is based upon facts which are believed to be established by the history of the development of the productive resources of this part of our territory. The commodities forming the bulk of the traffic for which provision is desired are grain (including flour), iron ore, lumber, and coal.

The movement of these commodities comprises about 90 per cent of the total freight movement on the lakes. As will be shown hereafter, the greater part of this traffic goes to the domestic markets of our country, but still an important part is destined to foreign markets. The volume of these products has increased rapidly with every increase in the facilities of transportation and with every permanent decrease in transportation rates. It is claimed that further increase in facilities

and reduction in rates is absolutely necessary if we would hold our place in foreign markets in competition with the products of other countries.

For the purposes of this inquiry full and accurate statistics of the lake commerce as it now exists are unnecessary, and indeed would be of little value. The problem involves conditions which will exist after a deep waterway has been established, and the quantitative effects of these conditions can not be determined from any existing data. Only such figures, therefore, are given as relate directly to the questions under consideration.

The following table[1] shows for the year 1898 the traffic for each of the four leading commodities referred to above, the eastward traffic (that is, the traffic east of Detroit), and the quantities destined to domestic and foreign markets, respectively:

[Quantities in net tons.]

| Commodity. | Total traffic. | Eastward traffic. | | |
|---|---|---|---|---|
| | | Total. | Domestic. | Export. |
| Grain (including flour) | 12,036,013 | 12,036,013 | 2,888,829 | *a* 9,147,184 |
| Iron ores | 13,650,788 | 11,028,321 | 11,028,321 | ..... |
| Lumber | 4,540,000 | 2,531,180 | 2,531,180 | ..... |
| Coal | 8,722,667 | ..... | ..... | ..... |
| Total | 38,949,468 | 25,595,514 | 16,448,330 | 9,147,184 |

*a* Exports from Montreal, Boston, New York, Philadelphia, and Baltimore.

To indicate the magnitude of the past development of this commerce it is only necessary to say that the total lake traffic for the year 1871 has been estimated at 14,283,000 tons. Since that time transportation facilities by rail and water have been greatly increased, new locks around the falls of St. Marys River have been constructed, the Welland Canal has been deepened, the lake harbors and channels have been improved, steam vessels have taken the place of sailing vessels, and the population of the country has about doubled. These are the principal causes of this enormous expansion of the volume of traffic.

FUTURE DEVELOPMENT OF LAKE TRAFFIC.

The population of the country will surely continue to increase rapidly, and this must be accompanied by an increase in the volume of the lake traffic. It must not, however, be inferred that the eastward traffic will develop in direct proportion to the increase in population of the country, for about one-half of our population is situated in the

[1] The figures for grain (including flour) are compiled from a report entitled The Grain Trade of the United States, published by the Bureau of Statistics of the Treasury Department, January, 1900. The other figures are based upon data obtained from the admirable tables which accompany the report of the committee on canals of New York State, 1899.

great Mississippi Basin, where the rate of increase is much greater than in our Eastern territory. The future demands of this part of our country upon the products of the lake region will doubtless reduce the relative amount of Eastern traffic. Nevertheless, it does not seem unreasonable to believe that the ratio of demand to supply will continue to be as great as it is at the present time, even should the facilities for transportation be very largely increased. The assumption that the difference in value of the freight unit at the terminals is constant for the transportation lines considered, which forms the basis of our equation of utility, seems, therefore, to be justified.

It appears from the table given above that only about one-third of the east-bound lake freight is exported to foreign countries, the remainder being distributed to domestic markets. Practically the entire exports of commodities transported on the lakes and received from the lake region consists of grain and other food products.

### GRAIN.

As regards the future development of the production of grain in the region tributary to the lakes, it is only necessary to point out that the rapid increase of our population will imperatively demand the utilization of all our food-producing areas in the near future for the supply of our own markets. It has been stated by Hon. John Hyde, Chief Statistician of the Agricultural Department, that within the short period of thirty years more than the entire wheat production of the country will be required for consumption by our own people, to the entire exclusion of our export trade.[1] Even should this view not be accepted by all, it must be admitted that the ratio of the export trade to the domestic trade in food products must rapidly diminish.

### IRON ORE.

The movement of iron ore, which forms at the present time so large a proportion of the lake traffic, is principally from Lake Superior to Lake Erie ports, from which the ore is sent by rail to the great coal and iron region of which Pittsburg is the center. As the undeveloped resources of the Lake Superior region are enormous, this traffic may increase greatly under the demands resulting from increased population. Should adequate facilities for water transportation be provided, it is possible that a considerable part of these products may be carried to points within the interior of the State of New York, where convenient limestone and the saving in cost of transportation both of the crude material and finished product may compensate for the advantage of the Pittsburg district in its greater proximity to coke and coal.[2]

[1] "America and the wheat problem." Published in The Wheat Problem, by Sir William Crookes, F. R. S.

[2] Report of committee on canals of New York State, 1899, p. 15.

None of this ore is exported at the present time, nor is it probable that much of it ever will be except in the form of finished material.

### LUMBER.

Of the four leading commodities considered lumber forms the smallest proportion of the lake traffic, and its movement is rapidly diminishing. The reasons for this rapid decrease are fully and clearly stated by Prof. George G. Tunell in his able report on lake commerce.[1] It is largely due to the destruction of the forests on the shores of the lakes and on the banks of the tributary streams. Lumber is now principally obtained at points so far in the interior that it is generally cheaper to saw logs at local mills and transport the product by rail than to carry or float them to the water and transship them. Moreover, there is a strong and increasing competition in northern markets from southern lumber. The exports of lumber from the lake region are now insignificant, and they must cease in the near future, as much more than our entire product will soon be needed for our own people.

### COAL.

The total volume of eastward traffic on the lakes greatly exceeds that of the westward traffic. The lake movement of coal, which is entirely westward, is therefore of great importance, not only because it supplies the necessities of the territory west and north of Lakes Michigan and Superior, but also because it furnishes a return freight for the lake carriers. Professor Tunell states that during 1896 coal constituted about three-fourths of the west-bound traffic through the Detroit River and 86 per cent of the west-bound traffic through the St. Marys Falls Canal.

Most of this material is shipped from the ports of Lake Erie to Duluth and Superior, at the head of Lake Superior, and to Chicago and Milwaukee, at the head of Lake Michigan, the shipments to Lake Superior being much greater than those to Lake Michigan, as in the latter case the conditions are more favorable for railway competition.

At the present time none of the coal transported on the lakes is sent to markets beyond sea, but if a deep waterway to the seacoast were constructed it would probably become an important factor in our export traffic.

### SUMMARY.

To summarize the above statements, the freight traffic of the Great Lakes, already amounting to at least 40,000,000 tons per year,[2] may be expected to increase greatly and rapidly with increase of population and the extension and cheapening of facilities for transportation,

[1] Doc. No. 277, House of Representatives, Fifty-fifth Congress, second session.

[2] The registered tonnage of the lake traffic for 1898, as given in the report of the New York State committee on canals, is 62,023,000. A large percentage of this is the registered tonnage of passenger steamers.

but this traffic will tend more and more to domestic markets and less and less to foreign ones.

CHARACTERISTICS OF TRANSPORTATION LINES.

These conditions appear to fully justify the establishment of new facilities for transportation from the lakes to the sea either by the General Government or by State or private enterprise. At the present time by far the greater part of the traffic between lake and ocean is by railway, only about one twenty-fifth of the volume transported going by canal and river. If a new line for water transportation is to be established it must be done by the General or a State Government, not only on account of the great expenditure involved, but also because such a line is not so desirable for private ownership and operation as a railway, upon which the carrier business can be monopolized by the owner, and therefore it probably would not be constructed by private enterprise. In order that we may clearly understand the consequences involved in the proposed change of the greater part of the traffic from rail to water transportation, we must now briefly point out the principal characteristics of railways and waterways considered as instruments of commerce for the transportation of freight.

It is frequently asserted that water transportation is always much cheaper than transportation by rail, but this statement can not be accepted without qualification. If it is intended to mean that the cost of transport proper is generally less in the case of the waterway than in the case of the railway, the statement is doubtless true; but if the toll is included in the cost of transport for the waterway as well as for the railway, the cost of transportation will often be less for the railway than for the waterway when the latter is an artificial channel of moderate dimensions.

As a line of communication between the same terminals, the railway is for obvious reasons almost always shorter than the water line. Moreover, it carries passengers, and a considerable part of its freight is of large value in proportion to its bulk. The passengers and high-class freight are made to bear a large proportion of the mean cost of transportation. A distinguished authority[1] on this subject finds from a study of experience on French railways and waterways that between two given points the mean net cost of transportation by rail is generally lower than the cost of transportation by water; but it must be remembered that the canals of France are of small dimensions and not well adapted to economical traffic. In short, no general rule on this subject can be laid down. Each case must be separately investigated, and the relative economical advantages of the rail and water way must be determined in accordance with the existing special conditions. Even then it is not easy to make a satisfactory comparison, owing to

[1] C. Colson, Ingénieur des Ponts et Chaussées, Maitre des Requêtes au Conseil d'Etat. Transports et Tarifs, Paris, 1890.

characteristic differences in the methods of conducting transportation by the two lines. Generally the railway carries passengers and a great variety of high-class as well as low-class freight, so that it is exceedingly difficult to determine the average cost of transportation of any assumed freight unit.

One of the most important differences between the railway and the waterway arises from the fact that in the case of the former the proprietor of the line and depots for receiving and shipping freight and the carrier are one and the same party, while in the case of the latter these interests are generally in different hands. It results from this that railway service is much more regular and efficient than water service, because it is under a centralized management.

The skill and efficiency with which the railway service is managed and improved and the lack of improvement and efficient management in canal transportation have often been pointed out, but it does not seem to have been observed that these differences are largely inherent in the different character of the organizations of the two services. The management of the railway is as much interested in the shipping, receiving, and movement of the traffic as in the toll, while in the case of the waterway each interest is concerned with the others only so far as may appear to be for its own direct benefit.

In the case of the waterway, especially when it is of small dimensions, delays are more liable to occur from accidents and crowding than in the case of the railway. The railway has generally the great advantage of speed, which secures for it all the traffic in which time of transport is an element of importance.

Finally, the railway is available for traffic during the whole year, while the waterway must be closed during the season of ice.

M. Colson remarks that experience shows that generally these advantages of the railway cause it to be preferred for the movement of merchandise of moderate value when the rates do not exceed those of water transportation by more than 20 per cent.[1] This deduction, however, is doubtless based upon a study of the traffic upon the railways and small canals of France.

The net cost of transportation upon the waterways herein considered, for both domestic and foreign traffic, would, of course, be very much smaller than on a railway or combined lake and railway line, even should the toll be included. Moreover, it is important that the facilities provided for increased traffic movement should be fully adequate to meet all possible future demands, and the waterways have a traffic capacity exceeding that which could be furnished by railways at the same cost.

The total freight tonnage of the New York Central and Hudson River Railroad in 1898 was 23,403,439 tons, which is much less than the maximum traffic capacity of the 21-foot waterway.

[1] Tarifs et Transports, p. 310.

An important advantage of the waterway over the railway results from the characteristic feature of its organization which has been already pointed out—that the various interests of line manager, freight shipper, and receiver and carrier are in different and independent hands. The maximum amount of benefit is derived from the traffic by the users of the line (or general public) when the toll and transport proper are made as small as possible. In the case of a railway, where the entire system is controlled by a single management, the natural effort is to obtain for the proprietor and carrier as much as possible of the value derived from the traffic; in other words, to make the traffic pay what it will bear. In the case of a large waterway open to the use of all carriers, the element of free competition regulates the rate of transport proper, and under these circumstances the charge for transportation must tend to approximate the net cost.

But it is not merely from the reduction of rates that benefit is derived. One of the most injurious effects of the lack of free competition in railway traffic has been the variation of rates through a wide range, resulting from alternate competition and combination of transportation lines. It has been found difficult, if not impossible, to control these variations by law; but the influence of a large waterway, open to the use of all carriers, could not fail to prevent large fluctuations in railway charges upon bulky freight during the season of its operation.

It has already been pointed out that this characteristic feature of waterways is a disadvantage so far as regards regularity of service and efficiency of management, and this is one reason why it may be considered desirable for the Government to own and manage the waterway and assume the toll. Under these circumstances the public will receive all the benefit derived from the traffic after the carrier has been paid his charges, and these charges will be kept from large fluctuation and near the net cost of transport by the action of free competition. It would, at first sight, seem unfair for the Government to assume the toll on one transportation line to enable it to compete to advantage with other lines constructed and operated by its own citizens; but it is claimed that the increased demand for a higher class of freight, created by the business and prosperity which would inevitably follow the construction of a great waterway, would more than compensate the railways for their loss of the low-class traffic. It would not be to the public interest to have the high-class traffic diverted from the railways to the waterways, but high-class freight is generally package freight not readily handled by mechanical devices, and therefore not likely to go by water.

This characteristic feature of water transportation controls not only the movement of the freight, but also its shipment and delivery. In the case of the railway, stations are established at which freight must

be handled under the direction of the management. In the case of the waterway, every point upon its banks is a possible station. The result must be an active competition, which must control and cheapen the cost of handling and develop points of shipment and delivery best suited to economical receipt and distribution.

It is claimed as a great advantage of waterways of sufficient dimensions for navigation by ships that they permit of the transport of the cargo through to domestic or foreign ports without transfer from one carrier to another, thus saving the time and cost of handling and loss by waste. This is an advantage of the ship canal as compared with the barge canal of moderate dimensions as well as with the railway. It is, however, considered by high authorities very doubtful whether a vessel can be so constructed as to navigate successfully and economically the ocean, the lakes, and the canal. The ocean vessel must be stronger than the lake vessel and more costly in construction, operation, and maintenance, and it must be fitted with expensive appliances which are not required in the lake traffic. In considering this question it must be remembered that under existing conditions the lake vessel is compelled to be idle during about one-third of the year, while if it had free access to the sea and were constructed for foreign or coast navigation it could be earning money all the year round.

Mr. Kirby estimates the cost of our type vessel No. 1, when designed for lake and ocean business, at $387,000, and when designed for lake business only, at $360,000. The daily cost of maintenance and operation, including 5 per cent on first cost, is, in the first case, $331, and in the second, $404. Such a vessel, when destined for lake and ocean business, could carry a full cargo from Duluth or Chicago to New York, and, owing to the additional buoyancy of sea water, then take on all the coal required for the ocean voyage without overloading.

The benefit to commerce which would result from giving access to shipping from the lakes to the sea, thus rescuing the lake fleet from enforced idleness during one-third of the year, would, of course, be enormous if the problem of constructing a vessel economically adapted to both kinds of service can be satisfactorily solved. This is a benefit which is peculiar to the waterway, and can not be derived from the extension of railway facilities.

It is further stated that if adequate water communication with the sea were provided a great industry in the construction of iron and steel ships would be immediately developed on the lakes. This industry is already an important one, no less than 1,258 vessels having been constructed at the lake ports during the last ten years; but as there is no access to the sea for vessels of more than about 13 feet draft, the business is almost exclusively confined to the construction of ships for the lake service.

It is claimed that nowhere in the world are the conditions for the

economical construction of steel vessels more favorable than at some of the lake ports. Cleveland, for example, is the center of a great steel manufacture. It is further from the coke-producing districts than Pittsburg, but this disadvantage is counterbalanced by its advantage of receiving ores by direct and cheap water transportation. The opening of a deep waterway to the sea would enable the shipyards of the lakes to compete with those of the seacoast in the construction of vessels for the ocean traffic.

Finally, the argument has often been advanced that a deep waterway connecting the lakes with the sea would be of great military value in connection with the defense of the northern frontier of the country Such a waterway would enable ships of war to pass between the sea and the lakes, and it would also permit the economical construction of such vessels at the lake shipyards.

The preceding brief statement of commercial and transportation conditions and of the benefits which may be expected to result from the establishment of a deep waterway from the lakes to the sea is intended only as a basis for the comparison of the relative advantages and disadvantages of the 21-foot and 30-foot waterways. Under the provisions of law, it is not the duty of the Board to report upon the general question as to whether the requirements of commerce justify the construction of a deep waterway at the expense of the General Government or to compare the advantages of such a waterway with those of one of moderate dimensions requiring transfers of freight at both its terminals. Nevertheless, before making the comparison required by law, it seems desirable to invite attention to two important points.

The first point is that if any project is undertaken by the Government it should be fully adequate to the present and future purposes which it is intended to subserve. It has been remarked by a distinguished authority that the life of any public work is practically coincident with that of the generation which began it. This is especially true in a country like our own, where population increases and commerce develops with amazing rapidity. The reason why it is true is because in the construction of such works future necessities are almost invariably underestimated. For example, the first canal and locks at St. Marys Falls were completed in 1855, at a cost of about $1,000,000. To meet the necessities of the increasing traffic, a new and much larger lock and canal were commenced in 1870 and completed in 1881, at a cost of $2,171,000. This was soon found to be insufficient for the requirements of the lake navigation, and still another and larger lock was commenced in 1887 and completed in 1896, at a cost of about $4,700,000. The volume of the lake traffic has so greatly increased that at the present time the construction of a new lock is under consideration. In 1870 no one could have been bold enough to suggest the construction of a lock of the size and cost

of the Poe lock, recently completed; and yet if such a lock had been then constructed the results would have been a large saving to the Government and a great benefit to the commercial interests of the lakes.

It is, therefore, of the highest importance that any waterway constructed by the Government should be fully capable of meeting every possible commercial demand which may arise in the future. A lack of capacity for future commerce might necessitate its entire reconstruction at enormous cost, and require an adaptation of vessels and traffic to new conditions, involving great loss to commercial interests.

The second point is that any project undertaken by the Government should be of a national and not of a local character, benefiting many and varied commercial interests and exerting its influence over as great an extent of the country as possible. It is easily conceivable that a barge canal of moderate dimensions, requiring transfers at Buffalo and New York, might be of more direct benefit to the State of New York than a canal of sufficient dimensions for the uninterrupted passage of ships, but much of this benefit would be at the expense of the producers and shippers of other parts of the country. Moreover, with such a canal the large interests of shipbuilding and winter traffic for the lake fleet would be unprovided for.

It appears from the investigations of the Board and the preceding discussion that the most favorable route for a 30-foot waterway from the lakes to the sea is from Lake Erie to Lake Ontario via La Salle and Lewiston, and from Lake Ontario to the Hudson River via Oswego and the Mohawk Valley, on the low-level plan, and that the same route is practically as favorable as any for the 21-foot waterway. The high-level plan gives a slightly greater return of direct value than the low-level plan for both the 21-foot and 30-foot waterways; but the difference is insignificant, and the Board considers the low-level plan preferable for engineering reasons. This route is entirely in our own country and has a longer season of navigation than the more northerly line. The problem of its defense is, of course, much simpler than it would be were a part of it in a foreign country, and it is available as a line of communication for ships of war. In the following comparison of the 21-foot and 30-foot waterways this route will alone be considered.

*Cost of construction.*—The estimated cost of the 21-foot waterway is $206,358,000; the estimated cost of the 30-foot waterway is $317,284,000, to which should be added about $9,607,500 for the necessary deepening of the harbors at Duluth and Chicago, making the total cost $326,892,000.

*Cost of maintenance and operation.*—The annual cost of maintenance and operation is estimated at $2,286,189 for the 21-foot waterway, and $2,883,158 for the 30-foot waterway.

*Cost of transport proper.*—The theoretical cost of moving the freight unit, exclusive of toll, from one terminal to the other on the lines considered, is given in the following table:

| Route. | 21-foot waterway. | | | | 30-foot waterway. | | | |
|---|---|---|---|---|---|---|---|---|
| | Domestic. | | Foreign. | | Domestic. | | Foreign. | |
| | Total cost. | Cost per ton-mile. | Total cost. | Cost per ton-mile. | Total cost. | Cost per ton-mile. | Total cost. | Cost per ton-mile. |
| New York to— | *Cents.* | *Mills.* | *Cents.* | *Mills.* | *Cents.* | *Mills.* | *Cents.* | *Mills.* |
| Duluth | 45.2 | 0.31 | 70.2 | 0.48 | 45.4 | 0.31 | 40.9 | 0.28 |
| Chicago | 42.3 | .31 | 67.3 | .49 | 42.7 | .31 | 38.2 | .28 |
| Mean | ..... | .310 | ..... | .485 | ..... | .310 | ..... | .280 |

It must be remembered that these values are purely theoretical, and are not given as the probable freight rates; but they are believed to be proportional to the latter and may, therefore, be taken as relative measures of the cost of transport proper for the waterways compared.

The table shows that the cost of transport proper on the 21-foot waterway is the same for domestic traffic as on the 30-foot waterway. For foreign traffic the 30-foot waterway shows a much lower cost of transport than the 21-foot waterway.

*Traffic capacity.*—The maximum annual traffic capacity of the 21-foot waterway (when the single-lift locks are duplicated) is estimated at 36,319,500 net tons, and that of the 30-foot waterway at 34,903,000 net tons, the traffic on the smaller waterway being greater than that on the larger one owing to the difference in time expended in lockage.

*Speed.*—The average speed on the 21-foot waterway is 10.67 miles per hour. The average speed on the 30-foot waterway is 10 miles per hour.

*Adaptability to traffic conditions.*—Our vessel No. 1, which is the type vessel adopted for the 21-foot waterway, has a draft of 19 feet, and can enter all the important lake harbors as well as navigate along the seacoast. It is therefore much better adapted to domestic traffic than vessel No. 7, the type vessel for the 30-foot waterway, since the latter has a draft of 27 feet and can not enter the lake harbors. The smaller vessel is not so well adapted to deep-sea navigation as the larger one.

*Regularity of service.*—In the 30-foot waterway navigation would be freer, and for smaller vessels a little more rapid than in the 21-foot waterway, and there would be less danger of delay from accidents and crowding. The time required for vessel No. 1 to make a single trip from Duluth to New York on the 30-foot waterway is six days and three hours, while the same journey on the 21-foot waterway would require two hours longer.

*Influence on railway rates.*—As both waterways furnish low rates for large traffic volumes, there seems to be little choice between them in this respect.

*Outlet for the lake fleet.*—Even should a 30-foot waterway be established between the lakes and the sea, it is probable that the number of vessels of large draft in the lake service would be comparatively small, since such vessels could not enter most of the lake harbors, and would be adapted only to through and principally foreign traffic. The 21-foot waterway would therefore be practically as good as the 30-foot waterway as a means of access to the sea for the lake fleet.

*Route for ships of war.*—In the very improbable event of a war with Great Britain, every large ship of war possessed by this country would be required on the high sea. Such vessels would be unnecessary on the lakes, since the greatest depth of the Canadian waterways is only 14 feet. For purposes of naval defense, the 21-foot waterway appears to offer ample facilities.

*Shipbuilding.*—The 30-foot waterway would enable the shipbuilders of the lakes to construct seagoing vessels of the largest size both for commercial and naval purposes. With the 21-foot waterway this industry must be restricted to the construction of vessels of not too great dimensions to pass the locks.

CONCLUSION.

As the result of this investigation, it appears that the 21-foot waterway promises a much greater return of value relatively to its cost than the 30-foot waterway. The main advantages of the 30-foot waterway are that it would furnish the lowest cost of transport proper to foreign markets and permit the construction of the largest seagoing vessels on the lakes.

Respectfully submitted.

C. W. RAYMOND,
*Lieutenant-Colonel, Corps of Engineers.*

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

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## APPENDIX NO. 6.

### LAKE ERIE REGULATION.

The act of Congress providing for a board of engineers on deep waterways requires that surveys and examinations be made on which to mature a project for controlling the level of Lake Erie, as recommended by the report of the Deep Waterways Commission, transmitted by the President to Congress January 18, 1897. In compliance with this requirement, I have the honor to submit for the consideration of the board the following discussion of lake levels, with plans and estimates of cost of regulating works designed for the purpose of maintaining the level of Lake Erie near its high-water stage during the navigation season.

The regulation of the level of a lake implies the maintenance of its surface at or near some fixed stage, to accomplish which the discharge must be so controlled that it will be at all times approximately equal to the difference between the supply of water to the lake and the evaporation from the surface.

In the Great Lakes system the watershed is about 2.4 times the area of the lake surfaces, and since the variation in the annual precipitation on the entire basin is approximately 50 per cent of the rainfall for a minimum year, and as the per cent of run-off from the watershed increases rapidly with increase of precipitation, it is probable that the actual supply for years of maximum rainfall is more than double that for years of minimum rainfall.

The surfaces of Lakes Michigan and Huron rise and fall at times at the rate of two-thirds of a foot per month, corresponding to a change of reservoir supply of 320,000 cubic feet per second. Assuming the discharge of the St. Clair River to be 190,000 cubic feet per second at the time that these changes occur,[1] it is evident that when the lakes are rising the supply at times exceeds 510,000 cubic feet per second, and when falling the supply becomes 130,000 cubic feet per second less than the evaporation from the lake surface, making the actual supply a negative quantity.

It is apparent, therefore, that with the evaporation from the lake surfaces at times largely in excess of total supply—which supply, including evaporation, has a range of over 600,000 cubic feet per second—any attempt to maintain the level of Lakes Huron and Michigan at a fixed stage would necessarily be a failure.

The storage capacity of Lake Superior amounts to 28,000 cubic feet per second annually for each foot in depth on the lake surface, and since the time of maximum discharge into Lake Huron is that when a large supply is necessary for the maintenance of the level of Lakes Huron and Michigan, it is apparent that any material modification of the range of water levels of Lake Superior would be an injury to the entire waterway system, and therefore the natural conditions on that lake should be maintained.

The storage of water in Lakes Superior, Michigan, and Huron, and the consequent fluctuations of the levels of those lakes, is absolutely essential for the maintenance of a flow through the connecting waterways sufficiently uniform for navigation purposes. While absolute regulation of the level of these lakes is an impossibility, a decrease of the fluctuations may be permissible, and will be considered elsewhere in connection with the indirect effect of the regulation of the level of Lake Erie on the depths of connecting waterways.

[1] The discharge of the St. Clair River is approximate, but is probably about 190,000 cubic feet per second for mean stages of Lakes Huron and St. Clair. The volume of discharge depends upon the level of both Lake Huron and Lake St. Clair, and is not constant for a given stage of the former.

The large areas of the water surfaces of the upper lakes serve as storage reservoirs during years of surplus rainfall on the lake basins, from which it is gradually discharged through the outlets during years of less than average precipitation. A variation in level of 1 foot for Lakes Superior, Huron, and Michigan is equivalent to a change in actual supply of 68,300 cubic feet per second for an entire year. The average rainfall on the lake basins tributary to Lake Erie is 31.64 inches per year, and is equivalent to 618,000 cubic feet per second for the same period, of which, approximately, 340,000 cubic feet per second either falls on or flows into the lakes, and 278,000 is either absorbed into the land on which it falls or is evaporated from vegetation and surfaces of ponds, streams, and marshes. About 120,000 cubic feet per second of the average annual supply to the lake reservoir system is taken up by evaporation and 220,000 cubic feet per second discharged through the Niagara River.

The run-off and evaporation are approximate quantities and are based on the result of observations made where the conditions were somewhat similar to those of the lake basin. So far as this discussion is concerned, a knowledge of the absolute values of these quantities is not necessary, as the relation of net supply and storage to the flow through the connecting waterways is so apparent that the approximate values used are sufficiently accurate to show the limits within which the storage capacity of the reservoir system may be modified without material injury to the navigable channels. The evaporation is to a great extent a function of the temperature of the air and water, and of the force of the wind, and may differ materially from results obtained at experimental observation stations.

The Rochester observations indicate that the evaporation for Lake Erie is probably 30 to 36 inches annually, while on Lake Superior the best data available indicates that the evaporation is less than one-half this amount.

The amount of water which the ground of any given watershed will absorb is about the same for each year, provided the supply is adequate, and therefore the run-off from watershed is a function of the difference between the precipitation and the amount absorbed, and not a direct percentage of the average rainfall for a series of years.

The annual precipitation on the Lakes Huron-Michigan basin varies from 27 to 40 inches, while the average absorption on the watershed is about 22 inches, from which it will be seen that the run-off during a wet year might be from two to three times that for a dry year, or a volume equivalent to over 3 feet in depth on the entire lake surfaces. This supply will not, however, produce a rise of 3 feet, for the reason that the volume of discharge through the outlets increases rapidly with increase of stage in the lakes. The maximum change of stage for any one year on Lakes Superior, Michigan, Huron, and Erie does not exceed 2.25 feet, while the extreme change during any series of years is about twice that amount.

This extreme change of level fixes the maximum stage necessary for taking care of the flood waters of the lake basins during a series of wet years, and the minimum limit which can be fixed for the fluctuation of any lake is that which will permit sufficient storage to insure an adequate flow for navigation through the connecting waterway during any series of dry years which are likely to occur.

The following table gives the area of the surfaces of the Great Lakes and watersheds, as determined by the best authorities:

| Lake— | Authority. | | | Area of watershed. |
|---|---|---|---|---|
| | L. Y. Schermerhorn. | L. E. Cooley. | T. Russell. | |
| | *Sq. miles.* | *Sq. miles.* | *Sq. miles.* | *Sq. miles.* |
| Superior | 31,200 | 31,800 | 32,060 | 48,600 |
| Michigan | 22,450 | 22,400 | 22,336 | 45,700 |
| Huron | 23,800 | 23,200 | 22,978 | 52,100 |
| St. Clair | | 495 | 503 | 6,320 |
| Erie | 9,960 | 10,000 | 9,968 | 24,480 |
| Ontario | 7,240 | 7,450 | 7,243 | 25,530 |

The values given by Mr. Cooley have been used in this discussion with the exception of that for Lake Erie, the area of which has been redetermined in this office and found to be 9,932 square miles.

The average annual rainfall on the lake basins, as furnished by the United States Weather Bureau, is as follows:

| | Inches. |
|---|---|
| Lake Superior | 28 |
| Lake Michigan | 33 |
| Lake Huron | 32 |
| Lake St. Clair | 35 |
| Lake Erie | 36 |
| Lake Ontario | 33 |

Assuming the run-off from the watersheds for a year of average precipitation to be 42 per cent for Lake Superior and 33 per cent for Lakes Michigan, Huron, and Erie, the distribution of the flow through the waterway system will be, approximately, as follows:

| *Lake Superior* (area of watershed 1.53 times area of lake surface): | Depth on lake. | |
|---|---|---|
| Rainfall on lake surface | feet | 2.33 |
| Run-off from watershed | do | 1.50 |
| Total supply | do | 3.83 |
| Evaporation from lake surface | do | 1.25 |
| Discharge through St. Marys River (72,000 cubic feet per second) | do | 2.58 |
| Total | do | 3.83 |

| *Lakes Michigan and Huron* (area of watershed 2.15 times the area of lake surfaces): | Depth on lakes. | |
|---|---|---|
| Rainfall on lake surfaces | feet | 2.7 |
| Run-off from watershed | do | 1.9 |
| Inflow from St. Marys River (72,000 cubic feet per second) | do | 1.8 |
| Total supply | do | 6.4 |

| *Lakes Michigan and Huron*—Continued. | | Depth on lakes. |
|---|---|---|
| Evaporation from lake surfaces | feet | 1.7 |
| Discharge through St. Clair River (190,000 cubic feet per second) | do | 4.7 |
| Total | do | 6.4 |

| *Lake Erie* (area of watershed 2.46 times area of lake surface): | | Depth on lake. |
|---|---|---|
| Rainfall on lake surface | feet | 3.0 |
| Run-off from watershed | do | 2.5 |
| Inflow from Detroit River (195,000 cubic feet per second) | do | 22.2 |
| Total supply | do | 27.7 |
| Evaporation from lake surface | do | 2.6 |
| Discharge through Niagara River (220,000 cubic feet per second) | do | 25.1 |
| Total | do | 27.7 |

The variation in the annual rainfall on the lake system amounts to 12 inches over the entire basin and is equivalent to a depth of 27 feet over the surface of Lake Erie, whereas the maximum storage which has occurred in any one year on Lake Erie only amounted to 2.16 feet in depth, with an average of 1.17 feet, or less than 5 per cent of the mean discharge of the Niagara River, and only one twenty-third of the total variation of the annual rainfall on the drainage basin tributary to the lake.

### EFFECT ON LEVEL OF LAKE ONTARIO AND ST. LAWRENCE RIVER.

To regulate the level of Lake Erie so as to maintain its surface near some fixed plane of reference will require such control of the outflow through Niagara River that the storage which would naturally occur in the lake will be discharged during the first half of the year and the outflow be diminished a like amount during the last half of the year. This modification of outflow will not materially change the total volume of discharge for any entire year, and will amount to only one-fifth of the variation of discharge of the river for different years under present conditions.

The effect of this modification of flow through Niagara River on the level of Lake Ontario will be to slightly increase the rate of rise in the spring and make the date of maximum stage a little earlier.

No reliable data exist from which the increment of discharge of the St. Lawrence River for 1-foot change of stage can be determined, but since the average annual fluctuation of the lake is 30 per cent greater than for Lake Erie, while the area of surface is only 25 per cent less than that of Lake Erie, it is evident the increment for the St. Lawrence does not differ much from that of the Niagara, a condition which would have a tendency to make any change of levels due to modified inflow very small.

The following table shows the stage and rise of Lake Ontario from January to June, and the inflow from Niagara River each year since 1865:[1]

| Year. | Elevation in— | | Rise. | Average inflow from Niagara River, January to July, per second. | Year. | Elevation in— | | Rise. | Average inflow from Niagara River, January to July, per second. |
|---|---|---|---|---|---|---|---|---|---|
| | January. | June. | | | | January. | June. | | |
| | *Feet.* | *Feet.* | *Feet.* | *Cubic feet.* | | *Feet.* | *Feet.* | *Feet.* | *Cubic feet.* |
| 1865 | 247.17 | 247.75 | 0.58 | 212,388 | 1882 | 245.82 | 247.62 | 1.80 | 245,758 |
| 1866 | 5.55 | 6.01 | .46 | 212,818 | 1883 | 5.41 | 7.58 | 2.17 | 227,523 |
| 1867 | 6.04 | 8.57 | 2.53 | 222,805 | 1884 | 6.60 | 8.18 | 1.58 | 243,356 |
| 1868 | 4.60 | 6.63 | 2.03 | 208,909 | 1885 | 6.23 | 7.53 | 1.30 | 223,576 |
| 1869 | 5.31 | 7.06 | 1.75 | 212,885 | 1886 | 7.69 | 8.53 | .84 | 239,381 |
| 1870 | 7.35 | 8.72 | 1.37 | 237,676 | 1887 | 6.26 | 8.25 | 1.99 | 245,243 |
| 1871 | 6.15 | 7.15 | 1.00 | 224,819 | 1888 | 5.53 | 6.37 | .84 | 217,906 |
| 1872 | 4.82 | 5.38 | .56 | 197,013 | 1889 | 5.71 | 6.72 | 1.01 | 214,043 |
| 1873 | 4.40 | 7.01 | 2.61 | 208,451 | 1890 | 6.34 | 8.25 | 1.91 | 232,920 |
| 1874 | 6.44 | 7.35 | .91 | 235,603 | 1891 | 6.28 | 6.92 | .64 | 216,876 |
| 1875 | 4.82 | 5.96 | 1.14 | 204,366 | 1892 | 4.60 | 5.90 | 1.30 | 202,288 |
| 1876 | 5.40 | 8.39 | 2.99 | 247,328 | 1893 | 4.96 | 7.46 | 2.50 | 207,470 |
| 1877 | 5.98 | 6.52 | .54 | 223,787 | 1894 | 5.65 | 6.89 | 1.24 | 208,594 |
| 1878 | 5.57 | 7.06 | 1.49 | 237,887 | 1895 | 4.58 | 4.97 | .39 | 189,048 |
| 1879 | 6.90 | 6.92 | .02 | 220,832 | 1896 | 3.89 | 5.43 | 1.54 | 189,141 |
| 1880 | 5 41 | 6.60 | 1.19 | 225,757 | 1897 | 3.97 | 5.71 | 1.74 | 203,471 |
| 1881 | 4.83 | 6.30 | 1.47 | 216,054 | 1898 | 4.73 | 6.22 | 1.49 | 211,834 |

Comparing the water level of Lake Erie for 1876 with that for 1895, it will be seen from table on page 287 that the actual supply to Lake Erie varies by 50 per cent of that for a minimum year, and that the discharge of the Niagara River varies 30 per cent for extreme stages of the lake. If an absolute variation of 30 per cent of the supply to Lake Ontario from the Niagara River does not produce any serious results, a change of 5 per cent of the flow from the first to the last half of the year would certainly have no material effect on depth of waterways.

On plate 81 a curve showing the level of Lake Ontario since 1865 has been platted from the monthly mean elevations of the lake, and another curve showing the monthly inflow from the Niagara River, in which the unit of the ordinates represent the number of cubic feet per second necessary to raise the level of the lake 1 foot in one month.

Assuming the discharge through the Niagara and St. Lawrence rivers at any given time to be approximately the same, the monthly difference of ordinates of Niagara discharge curve will represent the effect of the change of volume of inflow on the level of the lake, and the difference in the ordinates of the two curves will represent the excess of local supply over evaporation when the lake is rising, and the excess of evaporation over local supply when the lake is falling. It is very evident, both from table and from the curves, that any small modification of the flow of the Niagara which does not materially increase or diminish the total annual discharge through the river can not affect the depths of the Lake Ontario and St. Lawrence River waterways to any material extent.

[1] All elevations given in this report are referred to mean tide at New York and are based on the elevation of bench mark at Greenbush, N. Y., which is 14.73 feet.

If it should be found desirable to control the discharge of the St. Lawrence River within such limits as to reduce the fluctuation of 5.5 feet on Lake Ontario, under present conditions, to one-half that amount or less, it can be easily and cheaply accomplished by regulating works at the head of the Galop Rapids.

The St. Lawrence River above the Galop Rapids is of large cross-section and has nearly the same slope for all stages of the river.

At the head of Galop Island the river separates into two main channels, with heavy rapids in each. The channel on the north side of the river can be enlarged at the head of the rapids and provided with regulating works, which would greatly reduce the annual fluctuation of the lake levels.

The physical features and conditions at this locality are discussed in report on the St. Lawrence River surveys.

### EFFECT ON THE CONNECTING WATERWAYS OF THE UPPER LAKES.

The effect on the Lake Ontario and St. Lawrence River waterways which would arise from the control of the outflow of the Niagara River would be practically that due to distributing about 5 per cent of the inflow from the Niagara River over a different portion of the year than under natural conditions, but the effect of Lake Erie regulation on levels of Lake Michigan, Lake Huron, St. Clair and Detroit rivers will be of an entirely different nature, arising from the fact that the low-water levels will be permanently raised, the river slopes decreased for any given volume of discharge, and a redistribution of the flow due to a greater variation of the St. Clair River slopes than those arising from the natural change of lake levels.

The average annual fluctuation of Lake Erie is greater than that of Lake Huron, and consequently the slope of the connecting waterway is greater for the low-water stages of the lakes than at high stages, a condition causing a greater low-water discharge and a smaller high-water discharge, through the St. Clair and Detroit rivers, than would be the case with the surface of Lake Erie regulated at some fixed elevation.

During the season of navigation the fall of the St. Clair and Detroit rivers has an average annual variation of less than 0.50 foot each, with a total variation between Lake Huron and Lake Erie of about 1 foot, from which it is apparent that the variation of the outflow from Lake Huron is largely a function of the change in area of cross-section of outlet, due to change of stage.

During the winter season the freezing over of the St. Clair River diminishes the flow into Lake St. Clair to such an extent that the level of that lake usually falls considerably with reference to both Lake Huron and Lake Erie, making an abnormally steep slope in the St. Clair and a very low slope in the Detroit River. (See plate 83.)

Previous to 1886 the average fall from Lake Huron to Lake Erie was 9.2 feet, after which date the slope gradually diminished until 1890, since which time it has had an average of 8.3 feet. This decrease of slope was caused by the deepening of the river channels at the St. Clair Flats and at the Limekiln Crossing by the Government, and by the great increase from natural causes in depth and cross-section of the St. Clair River through the rapids at the outlet of Lake Huron.

A survey made at the request of this board in December, 1898, by a party under the direction of Lieut. Col. G. J. Lydecker, Corps of Engineers, United States Army, shows that the gorge at the head of the river now has a central depth of 66 feet and a cross-section of 36,000 square feet, whereas at the date of previous survey, in 1867, the central depth was only 48 feet and the cross-section 30,000 square feet. While there are no records to show when the deepening of channel through the rapids occurred, a study of the water levels and slope curves shown on plate 83 indicates that the erosion was probably started in the spring of 1886 by the abnormal fall (7.5 feet) of the St. Clair River at that time.

The average fall of the surfaces of the rivers previous to 1886 and since 1889 was as follows:

| | St. Clair River. | Detroit River and St. Clair Flats Canal. |
|---|---|---|
| | *Feet.* | *Feet.* |
| 1873 to 1886 | 5.7 | 3.5 |
| 1889 to 1898 | 5.0 | 3.3 |
| Decrease in slope | .7 | .2 |

It is probable the 0.7-foot decrease of slope in the St. Clair is due to the change of cross-section through the rapids at the head of the river, and that the 0.2-foot change of slope in the Detroit River and St. Clair Flats is due to the increased depth of channels from Government improvements.

To determine what the effect of change of stage in Lakes Huron and Erie has upon the slopes of the connecting waterway a line of precise levels was run, under the direction of this board, from Lake Erie to Lake Huron, and connections made with 15 different gauges at critical points on the rivers, which were read simultaneously for a week at two different periods, when the stage of the lakes had a difference of 0.66 foot.

The profiles of these slopes are shown on plate 82, which, in connection with curve of the monthly mean slopes of the Detroit and St. Clair rivers from 1873 to 1898, shown on plate 83 indicate that if the low-water stage of Lake Erie be raised and maintained 3 feet above its natural elevation the corresponding low-water stage of Lake St. Clair would be raised 2 feet and that of Lake Huron 1 foot, making the resulting

low stage for Lakes Huron and Michigan approximately what it was before being lowered by the deepening of the river channels. A rise of 0.66 foot in both Lake Huron and Lake Erie produced 0.56-foot rise in Lake St. Clair, with a largely increased volume of discharge through the waterway.

If the change of level in Lake St. Clair had been produced by raising the level of Lake Erie without changing the volume of flow, the surface of the former would have been raised only 0.45 foot, or a change of 3 feet in the level of Lake Erie by regulation will raise the level of Lake St. Clair 2 feet. An increase of 3 feet in the low-water level of Lake Erie would wipe out the entire fall now existing in the Detroit River for that stage, and the level of Lake St. Clair would rise until the slope and cross-section of the Detroit River was sufficient to maintain the low-water discharge, which existing data indicate would be about 2 feet.

If the low-water stage of Lake St. Clair should be increased 2 feet, the flow of the St. Clair River would be diminished to such an extent that Lake Huron would rise 1 foot before the normal low-water flow would be established.

The increase of the cross section of the Detroit River for the regulated stage over that at its natural low-water stage would be such that two-thirds of the low-water slope would be sufficient to produce approximately the same volume of flow in each case. The total variation of slope would still be about 1 foot, as under present conditions, and would limit the fluctuation of Lake St. Clair to the same amount.

The total variation of the slope of the St. Clair River when not affected by ice is about 1 foot, and since the cross section of the proposed regulated waterway would be greater than at the natural low-water stage, it is safe to assume that the slopes necessary to produce the same annual volumes of discharge as in the past will be less, and taken in connection with the fact that Lake St. Clair will have a fluctuation of about 1 foot, would indicate that the levels of Lakes Michigan and Huron will seldom have a variation of 2 feet, except in years of excessive rainfall on the lake basin, when the natural high-water stage would likely be reached. But since the deepening of the channels of the Detroit and St. Clair rivers has permanently lowered the levels of Lakes Huron and Michigan by about 1 foot for all similar conditions of supply and discharge, the high-water stage of those lakes for the future will be at least a foot lower than for similar seasons previous to 1890. The regulation of Lake Erie will, therefore, raise the present low-water stage of Lakes Michigan and Huron by about 1 foot and diminish the fluctuation of the levels the same amount.

The slope of the St. Clair River and the resulting discharge will be less in winter under the proposed conditions than at present. This, however, only applies to the ice period on the St. Clair River.

Under present conditions the slope of the waterway from Lake

Huron to Lake Erie decreases slightly as the lakes rise but with the level of Lake Erie maintained at a fixed stage the slope would vary with the stage of water in Lake Huron, and consequently the discharge would become a function of the hydraulic head at the outlet of the lake, a condition requisite for taking care of a maximum variation of supply to the lake reservoirs with a minimum fluctuation of the surfaces.

The area of Lake Erie is so small compared with that of Lakes Superior, Huron, and Michigan that its reservoir capacity is only one-ninth that of the upper lake system and if eliminated from the system by regulation the storage capacity remaining would be ample to maintain the connecting waterways so that the low-water stages would always be 3 feet higher in Lake Erie, 2 feet in Lake St. Clair, and 1 foot in Lake Huron than it is under the present conditions.

If the channel from Lake Huron to Lake Erie should be made 30 feet deep, the cross section of the waterway would be increased 600 square feet at the shallow places for each foot in depth that the channel is deepened at the respective shoals, which would decrease the slope requisite for any given volume of flow and slightly lower the low-water plane for both Lake Huron and Lake St. Clair.

The portion of the waterway over which this improvement would be distributed is comparatively short, and the total reduction of fall between the two lakes would probably be less than 0.3 foot, but is not susceptible of exact determination.

## REGULATION OF LAKE ERIE.

To determine the limits within which the level of Lake Erie is susceptible of being controlled by properly constructed regulating works, the Board has caused careful surveys and examinations to be made to determine the topography, hydrography, and character of material on which structures would have to be founded at foot of the lake and in the head of Niagara River, and a long series of observations to establish law of flow for the discharge through Niagara River for different stages of the lake. A series of observations has also been made for the board at the hydraulic laboratory of Cornell University, by Prof. Gardner S. Williams, to determine the coefficients of the formula for discharge over submerged weirs when the depth of water on crest of weir was greater than that for which the coefficients have heretofore been determined.

The two different plans which have been generally advocated for controlling the levels of the lakes are, to construct a dam, with regulating sluices, across the Niagara River below Tonawanda, N. Y., or to construct a submerged weir in connection with a set of regulating sluices at the foot of the lake, just below Buffalo Harbor.

A preliminary study of the problem and estimate of cost of regulating works, based on these surveys and examinations, developed the fact

that the first of these plans would require an expensive dam with lock and waste weirs in the Niagara River on each side of Grand Island, the excavation of over 5,000,000 cubic yards of material in the head of the river, the purchase of at least $3,000,000 worth of property which would be ruined by the works and high water along the river front, and the construction of several miles of dikes to safely maintain the impounded water above the level of adjacent country. The distance from Lake Erie to the site where dam would have to be constructed is 12 miles, on which the high-water slope of the river is about 8.5 feet. With the river improved by regulating works and enlarged cross section of channel through the gorge, this high-water slope would be reduced to about 2.5 feet and the low-water slope to 1.5 feet, making the fluctuation of the lake due to change of slope in river for different volumes of discharge approximately 1 foot, which would be increased 0.5 foot by change in velocity head at foot of lake, or a total probable fluctuation of 1.5 feet when the discharge of river is controlled by regulating works for maintaining the river at a fixed stage at a point 12 miles below outlet of lake.

The total cost of the project, including damages and the necessary drainage channel for taking care of Tonawanda Creek and the water from adjacent country, would be over $12,000,000, which, with the fact that the lake would still have considerable fluctuation, practically eliminates all chances of the plan receiving favorable consideration.

If a deep waterway should ever be constructed from Lake Erie to Lake Ontario via the Tonawanda-Olcott route, the improvement of the river by regulating works below Tonawanda would diminish the cost of the canal about $6,000,000, which would still leave a balance of $6,000,000 chargeable to the project.

Regulation of the lake levels by means of controlling works in the foot of Lake Erie will require either a submerged weir of such length that the change of discharge over crest of weir, due to a few inches variation of stage of lake, will be equivalent to a variation of outflow through the gorge at the head of the river due to 3-foot change in depth of river, or a short submerged weir in connection with a set of regulating sluices so designed that, with the sluice gates all closed, the low-water flow for the regulated stage of the lake will be discharged over the fixed submerged weir, and with the sluice gates all open the additional volume of outflow necessary to maintain the lake at nearly the same level will pass through the sluices at times when the lake is receiving its maximum supply.

The surveys and examinations indicate that a combination of a fixed weir and regulating sluices is better adapted for an economical and complete control of the lake level than by means of a fixed weir, and the plans and estimates submitted are for such a project.

In order to properly proportion the height of the weir and the width of sluices, and determine limits within which such works will control

the level of the lake, the observations for determining the volume of discharge of the Niagara River were made for as many different stages of the lake level as possible, and the following equation established, showing the outflow for any given elevation of the lake, viz, $Q=168{,}812+17{,}762\ y+1{,}409\ y^2$.

In which Q=the volume of discharge and $y$=the elevation of the lake at Buffalo in excess of 570 feet above tide water; or $y$=stage of lake−570 feet.

In connection with the direct observations made to determine the outflow from the lake at different stages continuous readings were made with gauges from which the slope of the foot of the lake and the river surface has been computed for the corresponding volumes of discharge, which, with the carefully measured cross sections of the river shown on plate 84, furnishes a check on the equation of discharge given above and shows a discrepancy of less than 3 per cent for maximum volume of outflow used in this discussion.

It has been found from an examination of the records of the lake water gauges at Buffalo, Cleveland, and the mouth of the Detroit River that the relative elevations of the gauges have been incorrectly established, and that the zero of the Cleveland gauge is 0.30 foot high, relative to the gauge readings at Buffalo, and 0.48 foot high as compared with that at the mouth of the Detroit River.

There is some uncertainty in regard to the stability of the gauge at Buffalo previous to 1896, and since the level of the lake is least affected by winds during the months of June, July, and August, the comparison of levels at Cleveland and Buffalo is based on the gauge readings for these months during 1896, 1897, and 1898, which are as follows:

*Elevation of lake.*

| Date | Buffalo gauge. | Cleveland gauge. | Difference. |
|---|---|---|---|
| | *Feet.* | *Feet.* | *Feet.* |
| 1896 | 571.57 | 572.01 | 0.44 |
| 1897 | 572.23 | 572.66 | .43 |
| 1898 | 572.25 | 572.69 | .44 |
| Mean | | | .44 |
| Correction for slope in foot of lake | | | .13 |
| Zero of Cleveland gauge too high | | | .31 |

A series of observations was made with gauges established in the open lake outside of Buffalo Harbor during July and August, 1898, which, compared with the record of the Government gauge at Cleveland, makes the zero of the latter gauge 0.30 foot too high, relative to the elevation of the lake at Buffalo, which amount has been used in computing the following table of elevations of the lake from Cleveland gauge records:

*Monthly mean elevations of Lake Erie at Buffalo, N. Y., for years 1865–1898, inclusive.*

| Year. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | Means. Jan to June, inclusive. | Means. 1 year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| 1865 | 571.80 | 571.22 | 571.54 | 572.26 | 572.84 | 572.82 | 572.78 | 572.70 | 572.66 | 572.36 | 571.98 | 571.84 | 572.08 | 572.23 |
| 1866 | 1.57 | 1.41 | 1.80 | 2.38 | 2.60 | 2.86 | 2.97 | 2.72 | 2.66 | 2.65 | 2.41 | 2.42 | 2.10 | 2.37 |
| 1867 | 2.13 | 1.81 | 2.21 | 2.53 | 3.05 | 3.36 | 3.17 | 2.86 | 2.47 | 2.13 | 1.63 | 1.41 | 2.52 | 2.40 |
| 1868 | 1.21 | 0.83 | 1.42 | 2.25 | 2.70 | 3.09 | 3.09 | 2.54 | 2.27 | 1.82 | 1.66 | 1.45 | 1.92 | 2.02 |
| 1869 | 1.44 | 1.37 | 1.85 | 2.15 | 2.70 | 3.09 | 3.37 | 3.27 | 3.00 | 2.55 | 2.09 | 2.44 | 2.10 | 2.44 |
| 1870 | 2.68 | 2.91 | 2.68 | 3.33 | 3.54 | 3.51 | 3.55 | 3.50 | 3.25 | 2.87 | 2.57 | 2.45 | 3.11 | 3.07 |
| 1871 | 2.24 | 1.91 | 2.36 | 2.84 | 3.11 | 3.14 | 3.12 | 2.91 | 2.74 | 2.07 | 1.89 | 1.45 | 2.60 | 2.48 |
| 1872 | 1.37 | 1.13 | 1.04 | 1.24 | 1.68 | 2.05 | 2.04 | 2.01 | 1.78 | 1.61 | 1.28 | 1.05 | 1.42 | 1.52 |
| 1873 | 0.95 | 0.96 | 1.03 | 2.31 | 2.98 | 3.06 | 3.04 | 2.98 | 2.58 | 2.28 | 2.08 | 2.45 | 1.88 | 2.23 |
| 1874 | 2.84 | 2.89 | 2.92 | 3.09 | 3.18 | 3.25 | 3.28 | 3.12 | 2.66 | 2.22 | 1.80 | 1.59 | 3.03 | 2.74 |
| 1875 | 1.36 | 1.19 | 1.33 | 1.73 | 2.20 | 2.63 | 2.76 | 2.75 | 2.61 | 2.12 | 1.97 | 2.19 | 1.74 | 2.07 |
| 1876 | 2.15 | 2.71 | 3.36 | 3.88 | 4.20 | 4.31 | 4.20 | 3.90 | 3.73 | 3.20 | 3.28 | 2.94 | 3.44 | 3.49 |
| 1877 | 2.54 | 2.38 | 2.15 | 2.58 | 2.83 | 2.91 | 3.15 | 3.01 | 2.93 | 2.53 | 2.45 | 2.53 | 2.57 | 2.67 |
| 1878 | 2.61 | 2.75 | 2.88 | 3.30 | 3.56 | 3.56 | 3.56 | 3.32 | 3.19 | 2.84 | 2.64 | 2.72 | 3.11 | 3.08 |
| 1879 | 2.30 | 2.16 | 2.19 | 2.55 | 2.70 | 2.79 | 2.82 | 2.60 | 2.27 | 2.04 | 1.57 | 1.83 | 2.45 | 2.32 |
| 1880 | 2.33 | 2.37 | 2.51 | 2.67 | 2.94 | 3.05 | 3.14 | 2.90 | 2.67 | 2.23 | 2.15 | 1.81 | 2.65 | 2.56 |
| 1881 | 1.40 | 1.51 | 1.83 | 2.53 | 2.93 | 3.17 | 3.12 | 2.80 | 2.45 | 2.40 | 2.22 | 2.43 | 2.23 | 2.40 |
| 1882 | 2.90 | 2.90 | 3.35 | 3.57 | 3.77 | 3.92 | 3.85 | 3.71 | 3.44 | 2.99 | 2.67 | 2.16 | 3.40 | 3.27 |
| 1883 | 2.07 | 2.28 | 2.47 | 2.59 | 3.05 | 3.75 | 3.95 | 3.89 | 3.58 | 3.26 | 2.88 | 2.91 | 2.70 | 3.06 |
| 1884 | 2.58 | 2.84 | 3.03 | 3.58 | 3.85 | 3.93 | 3.71 | 3.55 | 3.12 | 2.79 | 2.31 | 2.24 | 3.30 | 3.13 |
| 1885 | 2.06 | 1.85 | 1.71 | 2.53 | 3.26 | 3.77 | 3.73 | 3.74 | 3.50 | 3.49 | 3.37 | 3.32 | 2.53 | 3.04 |
| 1886 | 3.34 | 2.61 | 2.42 | 3.30 | 3.60 | 3.70 | 3.68 | 3.47 | 3.23 | 3.00 | 2.59 | 2.64 | 3.16 | 3.13 |
| 1887 | 2.41 | 2.83 | 3.64 | 3.66 | 3.84 | 3.87 | 3.63 | 3.31 | 3.08 | 2.49 | 2.22 | 2.24 | 3.38 | 3.10 |
| 1888 | 2.06 | 1.79 | 1.89 | 2.52 | 2.77 | 2.90 | 3.05 | 2.95 | 2.51 | 2.14 | 2.20 | 2.08 | 2.32 | 2.40 |
| 1889 | 2.10 | 1.94 | 1.78 | 2.13 | 2.31 | 2.74 | 2.94 | 2.63 | 2.24 | 1.82 | 1.55 | 1.81 | 2.17 | 2.17 |
| 1890 | 2.17 | 2.46 | 2.58 | 3.07 | 3.41 | 3.78 | 3.40 | 2.96 | 2.77 | 2.58 | 2.55 | 2.32 | 2.91 | 2.84 |
| 1891 | 2.10 | 2.08 | 2.54 | 2.41 | 2.23 | 2.37 | 2.27 | 2.00 | 1.82 | 1.44 | 1.00 | 1.07 | 2.29 | 1.94 |
| 1892 | 1.10 | 0.89 | 0.93 | 1.49 | 2.29 | 3.05 | 3.17 | 2.82 | 2.50 | 1.94 | 1.61 | 1.34 | 1.62 | 1.93 |
| 1893 | 0.96 | 1.04 | 1.26 | 1.99 | 2.83 | 3.02 | 2.74 | 3.40 | 2.62 | 1.67 | 1.27 | 1.35 | 1.85 | 1.88 |
| 1894 | 1.63 | 1.51 | 1.54 | 1.94 | 2.33 | 2.63 | 2.52 | 2.15 | 1.98 | 1.66 | 1.42 | 1.35 | 1.93 | 1.89 |
| 1895 | 1.02 | 0.79 | 0.80 | 1.05 | 1.27 | 1.36 | 1.25 | 1.17 | 1.07 | 0.59 | 0.49 | 0.65 | 1.05 | 0.96 |
| 1896 | 0.75 | 0.67 | 0.62 | 1.07 | 1.45 | 1.72 | 1.60 | 1.81 | 1.49 | 1.25 | 0.88 | 0.91 | 1.05 | 1.19 |
| 1897 | 0.88 | 1.08 | 1.45 | 2.00 | 2.33 | 2.43 | 2.42 | 2.26 | 1.98 | 1.49 | 1.36 | 1.33 | 1.70 | 1.75 |
| 1898 | 1.38 | 1.58 | 1.84 | 2.42 | 2.57 | 2.60 | 2.38 | 2.18 | 1.80 | 1.60 | 1.48 | 1.31 | 2.07 | 1.93 |
| Mean 1865 to 1898, inclusive | | | | | | | | | | | | | 572.36 | 572.40 |

The uncertainty in regard to the stability of the Buffalo gauge previous to 1896, together with the excessive fluctuations of the lake levels at Buffalo, make the Cleveland gauge record much more reliable, and it therefore has been used in determining the mean monthly elevations of the lake.

By substituting the monthly mean elevations of Lake Erie from the above table in the formula for discharge of Niagara River, the following table has been made, giving the mean discharge of the river for each month from 1865 to 1898, inclusive:

*Monthly mean discharges of Lake Erie at Buffalo, N. Y., for years 1865–1898, inclusive.*

| Year. | Jan. | Feb. | Mar. | Apr. | May. | June. | July. | Aug. | Sept. | Oct. | Nov. | Dec. | January to June, inclusive. | | Twelve months. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | Total. | Mean. | Total. | Mean. |
| | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* | *Cu. feet per sec'd.* |
| 1865 | 205,349 | 192,581 | 199,510 | 216,154 | 230,624 | 230,108 | 229,082 | 227,041 | 226,632 | 218,580 | 209,507 | 206,266 | 1,274,327 | 212,388 | 2,590,835 | 215,903 |
| 1866 | 200,174 | 196,659 | 205,349 | 219,068 | 224,518 | 231,139 | 233,997 | 227,551 | 226,632 | 225,780 | 219,803 | 220,049 | 1,276,907 | 212,818 | 2,630,119 | 219,176 |
| 1867 | 213,040 | 205,577 | 214,949 | 222,772 | 236,097 | 244,403 | 239,280 | 231,139 | 221,283 | 213,040 | 201,510 | 196,659 | 1,336,838 | 222,806 | 2,639,749 | 219,971 |
| 1868 | 192,368 | 184,528 | 196,877 | 215,912 | 227,041 | 237,151 | 236,361 | 223,021 | 216,395 | 205,806 | 202,182 | 197,533 | 1,253,454 | 208,909 | 2,534,754 | 211,229 |
| 1869 | 197,314 | 195,793 | 206,496 | 213,516 | 227,041 | 237,151 | 244,075 | 241,963 | 234,779 | 223,271 | 212,090 | 220,543 | 1,277,311 | 212,885 | 2,652,632 | 221,063 |
| 1870 | 226,536 | 232,432 | 226,536 | 243,587 | 249,349 | 248,517 | 249,627 | 248,239 | 241,425 | 231,397 | 223,770 | 220,790 | 1,426,057 | 237,676 | 2,842,205 | 236,850 |
| 1871 | 215,672 | 207,879 | 218,580 | 230,624 | 237,681 | 238,481 | 237,948 | 232,432 | 228,061 | 211,619 | 207,414 | 197,533 | 1,348,917 | 224,819 | 2,665,924 | 221,994 |
| 1872 | 195,793 | 190,685 | 188,812 | 193,007 | 202,632 | 211,149 | 210,913 | 210,207 | 204,894 | 201,062 | 193,858 | 189,019 | 1,182,078 | 197,013 | 2,392,031 | 199,336 |
| 1873 | 186,961 | 187,165 | 188,605 | 217,361 | 234,257 | 236,361 | 235,833 | 234,257 | 224,019 | 216,635 | 211,854 | 220,790 | 1,250,708 | 208,451 | 2,594,096 | 216,175 |
| 1874 | 230,624 | 231,913 | 232,692 | 237,151 | 239,813 | 241,425 | 242,233 | 237,948 | 226,632 | 215,190 | 205,349 | 230,617 | 1,413,619 | 235,603 | 2,740,988 | 228,416 |
| 1875 | 195,578 | 191,945 | 194,931 | 203,760 | 214,708 | 225,275 | 228,572 | 228,317 | 224,770 | 212,801 | 209,274 | 214,469 | 1,226,197 | 204,366 | 2,544,400 | 211,200 |
| 1876 | 213,516 | 227,296 | 244,403 | 258,942 | 268,268 | 271,542 | 268,268 | 259,514 | 254,670 | 240,079 | 242,233 | 233,214 | 1,483,967 | 247,328 | 2,981,945 | 248,495 |
| 1877 | 223,021 | 219,068 | 213,516 | 224,019 | 230,366 | 232,432 | 238,747 | 235,043 | 232,953 | 222,772 | 220,790 | 222,772 | 1,342,722 | 223,787 | 2,715,499 | 226,291 |
| 1878 | 224,770 | 228,317 | 231,655 | 242,771 | 249,905 | 249,905 | 249,905 | 243,315 | 240,079 | 230,624 | 225,527 | 227,551 | 1,427,323 | 237,887 | 2,844,524 | 237,044 |
| 1879 | 217,118 | 213,754 | 214,469 | 223,271 | 227,041 | 229,337 | 230,108 | 224,518 | 216,395 | 210,913 | 200,174 | 206,636 | 1,324,990 | 220,832 | 2,613,134 | 217,762 |
| 1880 | 217,849 | 218,824 | 222,273 | 226,284 | 233,214 | 236,097 | 238,481 | 232,171 | 226,284 | 215,431 | 213,516 | 205,577 | 1,354,541 | 225,757 | 2,686,001 | 223,833 |
| 1881 | 196,440 | 198,846 | 206,036 | 222,772 | 232,953 | 239,280 | 237,948 | 229,592 | 220,790 | 219,556 | 215,190 | 220,286 | 1,296,327 | 216,054 | 2,639,699 | 219,975 |
| 1882 | 232,171 | 232,171 | 244,131 | 250,182 | 255,803 | 260,092 | 258,084 | 254,103 | 246,590 | 234,518 | 226,284 | 213,754 | 1,474,550 | 245,758 | 2,907,883 | 242,324 |
| 1883 | 211,619 | 216,636 | 221,283 | 224,269 | 236,097 | 255,237 | 260,959 | 259,228 | 250,460 | 241,694 | 231,655 | 232,432 | 1,365,141 | 227,523 | 2,841,569 | 236,797 |
| 1884 | 224,019 | 230,624 | 235,570 | 250,460 | 258,084 | 260,381 | 254,103 | 249,627 | 247,948 | 229,337 | 217,361 | 215,672 | 1,460,138 | 243,356 | 2,863,186 | 238,599 |
| 1885 | 211,384 | 206,496 | 203,306 | 222,772 | 241,694 | 255,803 | 254,670 | 254,953 | 250,737 | 247,964 | 244,675 | 243,315 | 1,341,455 | 223,576 | 2,837,769 | 236,481 |
| 1886 | 243,859 | 224,770 | 220,049 | 242,771 | 251,015 | 253,820 | 253,259 | 247,415 | 240,887 | 234,779 | 224,269 | 225,527 | 1,436,284 | 239,381 | 2,862,420 | 238,535 |
| 1887 | 219,803 | 230,366 | 252,137 | 252,698 | 257,797 | 258,656 | 251,857 | 243,043 | 236,888 | 221,776 | 215,190 | 215,672 | 1,471,457 | 245,243 | 2,855,883 | 237,990 |
| 1888 | 211,384 | 205,121 | 207,414 | 222,522 | 228,827 | 232,171 | 236,097 | 233,475 | 222,273 | 213,278 | 214,708 | 211,854 | 1,307,906 | 217,906 | 2,639,123 | 219,928 |
| 1889 | 212,324 | 208,576 | 204,894 | 213,040 | 217,361 | 228,061 | 233,214 | 225,275 | 215,672 | 205,806 | 199,732 | 205,577 | 1,284,256 | 214,043 | 2,569,532 | 214,128 |
| 1890 | 213,992 | 221,036 | 224,019 | 236,624 | 245,766 | 256,086 | 245,491 | 233,736 | 228,827 | 224,019 | 223,271 | 217,605 | 1,397,523 | 232,920 | 2,770,472 | 230,873 |
| 1891 | 212,324 | 211,854 | 223,021 | 219,803 | 215,431 | 218,824 | 216,395 | 209,972 | 205,806 | 197,314 | 187,983 | 189,433 | 1,301,257 | 216,876 | 2,508,160 | 209,013 |
| 1892 | 190,055 | 185,737 | 186,552 | 198,407 | 216,877 | 236,097 | 239,280 | 230,108 | 222,023 | 208,576 | 201,062 | 195,146 | 1,213,725 | 202,288 | 2,509,920 | 209,160 |
| 1893 | 187,165 | 188,812 | 193,432 | 209,740 | 230,366 | 235,306 | 228,061 | 219,557 | 210,443 | 202,406 | 193,645 | 195,362 | 1,244,821 | 207,470 | 2,494,295 | 207,858 |
| 1894 | 201,510 | 198,846 | 199,510 | 208,576 | 217,849 | 225,275 | 222,522 | 213,516 | 209,507 | 202,182 | 196,877 | 195,362 | 1,251,596 | 208,594 | 2,491,532 | 207,628 |
| 1895 | 188,397 | 183,724 | 183,923 | 189,019 | 193,645 | 195,578 | 193,220 | 191,525 | 189,433 | 179,783 | 177,852 | 180,956 | 1,134,286 | 189,048 | 2,247,055 | 187,255 |
| 1896 | 182,930 | 181,348 | 180,368 | 189,433 | 197,533 | 203,533 | 200,838 | 205,577 | 198,407 | 193,220 | 185,536 | 186,143 | 1,135,147 | 189,191 | 2,304,868 | 192,072 |
| 1897 | 185,536 | 189,641 | 197,533 | 209,972 | 217,849 | 220,296 | 220,049 | 216,154 | 209,507 | 198,407 | 195,578 | 194,931 | 1,220,827 | 203,471 | 2,455,453 | 204,621 |
| 1898 | 196,009 | 200,395 | 206,266 | 220,049 | 223,770 | 224,518 | 219,068 | 214,231 | 205,349 | 200,838 | 198,188 | 194,500 | 1,271,007 | 211,834 | 2,503,180 | 208,600 |
| Mean, 1865 to 1898, inclusive | | | | | | | | | | | | | 219,642 | | | 220,428 |

With a few minor exceptions the rise of the lake levels occurs during the first six months of the year, and since the actual net supply to the lake (inflow less evaporation) is equal to the sum of the volumes of storage and outflow, it follows that the area of the lake, multiplied by the change in level during storage period, plus the discharge, must equal the supply. Careful measurements from the best charts obtainable make the area of the lake 9,932 square miles, over which storage at the rate of 1 foot depth in six months is equivalent to an average supply of 17,540 cubic feet per second for the same period.

The following table gives the rise, average discharge, and average supply for the first six months of each year from 1865 to 1898, inclusive:

*Annual rise and supply to Lake Erie.*

| Year. | Rise for six months. | Equivalent per second. | Average discharge per second. | Average supply per second. | Year. | Rise for six months. | Equivalent per second. | Average discharge per second. | Average supply per second. |
|---|---|---|---|---|---|---|---|---|---|
| | *Feet.* | | *Feet.* | *Feet.* | | *Feet.* | | *Feet.* | *Feet.* |
| 1865 | 1.02 | 17,891 | 212,388 | 230,278 | 1882 | 1.02 | 17,891 | 245,758 | 265,649 |
| 1866 | 1.29 | 22,627 | 212,818 | 235,445 | 1883 | 1.68 | 29,467 | 227,523 | 256,990 |
| 1867 | 1.23 | 21,574 | 222,806 | 244,380 | 1884 | 1.35 | 7,893 | 243,356 | 251,249 |
| 1868 | 1.88 | 32,975 | 208,909 | 241,884 | 1885 | 1.71 | 29,983 | 223,576 | 253,559 |
| 1869 | 1.65 | 28,941 | 212,885 | 241,826 | 1886 | .36 | 6,314 | 239,381 | 245,695 |
| 1870 | .83 | 14,558 | 237,676 | 252,234 | 1887 | 1.48 | 25,608 | 245,243 | 270,851 |
| 1871 | .90 | 15,786 | 224,819 | 240,605 | 1888 | .84 | 14,734 | 217,906 | 232,640 |
| 1872 | .68 | 11,927 | 197,013 | 208,940 | 1889 | .64 | 11,226 | 214,043 | 225,269 |
| 1873 | 2.11 | 37,010 | 208,451 | 245,461 | 1890 | 1.61 | 28,240 | 232,920 | 261,160 |
| 1874 | .41 | 7,191 | 235,603 | 242,794 | 1891 | .27 | 4,736 | 216,876 | 221,616 |
| 1875 | 1.27 | 22,276 | 204,366 | 226,642 | 1892 | 1.95 | 34,203 | 202,288 | 236,491 |
| 1876 | 2.16 | 37,886 | 247,328 | 285,214 | 1893 | 2.06 | 36,132 | 207,470 | 243,602 |
| 1877 | .37 | 6,490 | 223,787 | 230,277 | 1894 | 4.01 | 17,715 | 208,594 | 226,309 |
| 1878 | .95 | 16,663 | 237,887 | 254,550 | 1895 | .34 | 5,964 | 189,048 | 195,012 |
| 1879 | .49 | 8,595 | 220,832 | 229,427 | 1896 | .97 | 17,014 | 189,191 | 206,205 |
| 1880 | .72 | 12,629 | 225,757 | 238,386 | 1897 | 1.55 | 27,187 | 203,471 | 230,658 |
| 1881 | 1.77 | 31,045 | 216,054 | 247,099 | 1898 | 1.22 | 21,399 | 211,834 | 233,233 |

With the lake level regulated at 574.5 feet above tide water, the maximum discharge will be 277,270 cubic feet per second.

The mean elevation of the lake at Buffalo for the years 1865 to 1898, inclusive, was 572.4 feet above tide water, for which the corresponding discharge is 219,560 cubic feet per second. The mean of all the monthly discharges for the same period is 220,430 cubic feet per second. The difference of these quantities, or the difference between the mean discharge and the discharge at the mean stage of the lake, is due to the increment of discharge for any given change of stage, being greater for high water than at low.

Assuming that the lake be regulated for a stage of 574.5 feet, or about 0.5 foot below the extreme high-water stage of the lake, the maximum limit to which the outflow could be increased would be 277,270 cubic feet per second, as shown by equation of discharge.

It will be seen from the above table that since 1865 there has been but one year (1876) in which the average supply during the storage season was in excess of the volume which will be discharged through the outlet when the lake is at the stage 574.5 feet above tide water.

The mean monthly supply for year of maximum storage, January to June, 1876, was as follows (per second):

| | Cubic feet. |
|---|---|
| January | 272,400 |
| February | 295,700 |
| March | 299,100 |
| April | 292,600 |
| May | 279,800 |
| June | 271,500 |
| Mean | 285,200 |

The three months in which the supply was materially in excess of the discharge for proposed regulated stage were February, March, and April, during which the excess averaged 19,000 cubic feet per second, corresponding to a rise of 0.2 foot in February, 0.2 foot in March, and 0.15 foot in April; hence if the level of the lake when regulated should be allowed to fall 0.6 foot each year after the close of navigation, it is probable that the excess of supply over discharge would never cause the surface to rise above the plane of regulation.

From an examination of the tables on pages 285 and 286 it will be seen that at the close of the navigation season the supply is always much less than the capacity of the regulating works and that during the storage period it is larger than the discharge over the fixed weir, and therefore it is always possible to lower the lake level any desirable amount in the fall of the year and to supply the deficiency at the beginning of the season of navigation.

Rules can be established such that when Lake Huron is at or above an average stage in the fall the surface of the lake may be lowered an amount such that any excessive local supply can be taken care of, and in case such local supply should be less than expected the normal level may be restored at the opening of navigation, after which date the supply to the lake usually diminishes.

In the fall of 1875 the discharge of Niagara River was 60,000 cubic feet per second less than the capacity of the regulating works, and if the lake had been regulated with the sluices of the regulating works all open the surface would have been lowered 1 foot in about two months, or sufficient to have stored the excessive supply which occurred in the spring of 1876, with a margin of 0.4 foot for contingencies.

It has been shown that the fall of the waterway from Lake Huron to Lake Erie under existing conditions is less at high stages of the lakes than at low, but if the level of Lake Erie be controlled at a fixed elevation the fall of the rivers would increase with the stage in Lake Huron and cause a larger discharge for any given rise than at present.

High water in Lakes Huron and Michigan occurs about one month after Lake Erie commences to fall, and any increase of the high-water discharge of the St. Clair River, arising from the regulation of Lake Erie, will take place after the supply to the latter lake becomes less

than the capacity of the regulating works and will tend to make the supply to Lake Erie greater in July and August and less in winter than under present conditions.

For example, the rise and storage in Lakes Michigan and Huron in 1876 (the year of maximum supply to Lake Erie) were as follows:

| Month. | Elevation of lake surface. | Rise per month. | Total rise. | Storage per second. |
|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Feet.* | *Cubic ft.* |
| January | 581.23 | | | |
| February | 581.21 | —0.02 | —0.02 | —800 |
| March | 581.34 | .13 | 11 | 52,170 |
| April | 581.62 | .28 | .39 | 135,350 |
| May | 582.22 | .60 | .99 | 290,040 |
| June | 582.71 | .49 | 1.48 | 296,970 |
| July | 583.15 | .44 | 1.92 | 212,800 |

The maximum supply to Lake Erie in 1876 occurred in March, at which time it will be seen from the above table that no material rise had taken place in Lake Huron, and therefore the excessive rise in Lake Erie was largely due to inflow from the watershed directly tributary to the lake and occurred nearly a month before the rise in Lake Huron was sufficient to materially increase the discharge through the St. Clair River.

The minimum stage of Lake Erie since 1865 occurred in November, 1895, when the surface was 570.5 feet above tide water and the discharge at the outlet 178,000 cubic feet per second, which, compared with that for March, 1876, indicates a maximum variation of outflow of 121,000 cubic feet per second.

With the exception of 1876 the average supply during storage period has not exceeded 271,000 cubic feet per second, corresponding to the discharge through Niagara River when the lake is at a stage of 574.3 feet above tide water, from which it is evident that when the lake is at its highest stage the outflow is practically equal to the maximum supply, and if such maximum inflow should continue constant for any length of time a practical state of regulation would exist. To establish regulation at any lower stage than 574.3 feet above tide water will require that the gorge at the head of Niagara River be enlarged sufficiently to allow a discharge equal to the maximum supply at that stage.

In order, therefore, to maintain the lake at a fixed stage it will be necessary to construct a fixed weir over which a discharge of about 178,000 cubic feet per second can be maintained at times when the water below the dam is 4 feet lower than the regulated surface of the lake (with stage of 570.5 below dam the discharge through gorge will be 178,000 cubic feet per second), and a set of sluices through which, in connection with the flow over the fixed weir, 271,000 cubic feet per second will be discharged when the sluice gates are all open.

For the purpose of obtaining this control of the outflow, it is proposed to construct a fixed weir 2,900 feet long with 6.6 depth of water on the crest, and 13 sluices, having 80 feet clear opening each and an aggregate cross-section of 23,800 square feet.

The following results are obtained from the records of gage readings made in 1897 and 1898 to determine the slope of the river for different stages of the lake:

| Stage of lake. | Fall from lake to dam site. | Mean velocity at dam site. | Theoretical velocity head. | Difference between fall and theoretical velocity head. |
|---|---|---|---|---|
| *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| 570.5 | 0.68 | 3.9 | 0.24 | 0.44 |
| 574.5 | .72 | 4.3 | .29 | .43 |

| Stage of lake. | Fall from lake to waterworks. | Mean velocity in section. | Theoretical velocity head. | Difference between fall and theoretical velocity head. |
|---|---|---|---|---|
| *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| 570.5 | 3.02 | 8.0 | 0.99 | 2.03 |
| 574.5 | 3.34 | 9.1 | 1.28 | 2.06 |

It will be seen from the above that the change of slope from the lake to the proposed site for regulating works and from the lake to the gorge in the head of the river varies with the theoretical head necessary to produce the velocity of flow at the respective sections, and that the amount of fall necessary to overcome friction and maintain the flow is practically constant within the limits under consideration.

With the proposed regulating works in place, the mean velocity of flow for maximum discharge through the works will be 6.4 feet per second, and, since the velocity at the gorge will always exceed that at the regulating works, the amount of additional resistance to be overcome after regulation is effected will be simply that due to maintaining the flow through the works, which is less than 0.025 foot.[1]

The maximum discharge for the lake, when regulated, will therefore be approximately the same as for the same stage under the present conditions.

The observations which were made for the board at the hydraulic laboratory of Cornell University to determine the coefficients for the Francis weir formula ($Q = CLh^{\frac{3}{2}}$) for the design of weir proposed for

[1] With a stage of 574.5 feet above tide water under present conditions, the water starting from a state of rest in the lake has a mean velocity of 4.3 feet per second at the proposed site for the regulating works and 9.1 feet per second across the section at the waterworks, and, under the new conditions which will arise from the construction of regulating works, the water will have a mean velocity of 6.4 feet at the dam and 9.1 feet per second at the waterworks, from which it is evident that the theoretical velocity head will remain unchanged, and that whatever change in total fall occurs will be due to the resistance to flow caused by the dam and sluices.

the regulating works, gives the following values for C when $h$ = depth on weir = 6.6 feet.

| Submergence from back water. | C in the formula, $Q = CLh^{\frac{3}{2}}$. |
|---|---|
| $h$. ′ | |
| 0.0=0.00 | 3.70 |
| 0.1=0.66 | 3.67 |
| 0.2=1.32 | 3.64 |
| 0.3=1.98 | 3.60 |
| 0.4=2.64 | 3.54 |
| 0.5=3.30 | 3.47 |
| 0.6=3.96 | 3.36 |
| 0.7=4.62 | 3.17 |
| 0.8=5.28 | 2.88 |
| 0.9=5.94 | 2.30 |

For a low-water discharge of the river the submergence below the weir will be $0.4^h$, making the value C = 3.54.

Assuming the length of the proposed fixed weir to be 2,900 feet, the discharge will be $Q = 3.54 \times 2{,}900 \times (6.6)^{\frac{3}{2}} = 175{,}000$ cubic feet per second; and, since a complete control of the lake level for minimum outflow requires that it should never be less than the capacity of the weir, it would appear that the proposed dimensions of weir are reasonably correct.

It has been shown that the mean velocity for maximum discharge through the regulating works will be 6.4 feet per second, which will require a theoretical velocity head of 0.64 foot to generate the current, and 0.43 foot to overcome friction and maintain flow, making a total fall of 1.07 feet from the lake to the site of regulating works, instead of 0.72 foot required under the present conditions.

Omitting the loss of head requisite to maintain flow above the works, the submergence from backwater will be, approximately, $0.9^h$, making the coefficient for the weir C = 2.30 and the discharge $Q = 2.30 \times 2{,}900 \times (6.6)^{\frac{3}{2}} = 113{,}400$ cubic feet per second.

The mean velocity of flow through the sluices will be 6.7 feet per second, which, multiplied by the total area of sluice cross section, gives a discharge of 159,500 cubic feet per second, and a total discharge past the regulating works of 272,900 cubic feet per second, an amount 1,900 cubic feet per second in excess of the average supply during the storage period for any year since 1865, except that for 1876.

A year of maximum supply similar to that of 1876 can only occur after one or more years of excessive rainfall over the entire lake basin, and when such conditions are known to exist the level of the lake can be allowed to fall sufficiently after the close of navigation each year to provide storage for any excess of supply that may be expected.

If for any reason it should be deemed advisable to regulate the level of the lake at a lower stage than 574.5 feet, it can be readily accom-

plished by enlarging the restricted cross section of the river at the gorge for a distance of about 3,000 feet.

The present low-water cross section of the river through the gorge is only 22,000 square feet area, and if enlarged 10 per cent the outflow for all stages of the water surface below the regulating works would be increased sufficiently to allow full control of the levels at a stage of 573.5 feet above tide water, which has been exceeded by the high-water level of the lake on eleven different years since 1870, and could not in any way be construed as likely to be of damage to vested rights.

Such an enlargement would necessitate the excavation of about 218,600 cubic yards of earth and 164,500 cubic yards of rock, and would cost about $384,000.

The proposed elevation for regulated stage of 574.5 feet above tide water is about 0.5 foot less than the extreme high-water stage of the lake and is considered a safe limit for construction.

## WIND EFFECT.

From the head of Lake Erie to the islands (about 30 miles) the depth of water is only about 35 feet, and through the channels between the islands the depth is from 25 to 35 feet.

Heavy westerly winds force the water through these passages into the main body of the lake, causing a lowering of the water level at the head of the lake and a corresponding rise at Buffalo. The amount of this change of level depends upon the stage of the lake, the velocity and direction of the wind, and the duration of the storm, and, in extreme cases, with wind velocity of 60 to 80 miles lasting for several hours the change of level reaches 6 to 7 feet at each end of the lake.

The change of level at Cleveland is generally less than 1 foot, showing that the wind effect is mostly at the two ends of the lake, and is due to the depth of water being so small that return currents are not generated sufficiently to equalize the effect of wind on the surface, until considerable difference in level is produced. The deeper the water, the less will be the head necessary to produce any given volume of flow in the return current, and it is probable that the elevation to which the water will be raised by wind of any given velocity and duration will be approximately the same, whether the lake be at extreme low or medium high stage when the storm occurs. Storms of sufficient force to change the water level 3 feet or more at the head of the lake are very infrequent, and can only be provided for by making the depth of channels at the head and foot of the lake that amount deeper than through other portions of the waterway system.

The length of time which these changes would be in excess of 1 foot is so small that, with the level of the lake regulated above mean stage, the detention from this cause would not seriously delay commerce.

## PROPOSED LOCATION OF WORKS.

Starting at a point on the breakwater of Black Rock Harbor, about 6,000 feet below the entrance at Buffalo Creek, a rock reef, with an average depth of 6.6 feet of water at proposed regulated stage, is utilized for a distance of 1,300 feet to the bank of the channel of the outlet, at which place the line of the works makes a deflection of 35° and extends to the Canadian shore, a distance of 2,810 feet, of which 1,600 feet is to be a fixed weir, 1,040 feet sluice openings, and 170 feet sluice-gate piers, as shown on plate 84.

The site is protected from winds from all directions, except from the south to the southwest, and has a rock bottom suitable for the foundation of structures for the entire width of cross section. The rock reef from the Black Rock Harbor breakwater to the west end of the system of proposed sluice gates has approximately the elevation required for a fixed weir, and will need but a small amount of excavation (given in estimate) to make it suitable for 1,200 feet of the proposed submerged portion of regulating works. (See plate 84.)

## DESIGN OF STRUCTURES.

The fixed weir and the piers for regulating sluices have been designed with reference to securing a maximum volume of discharge for any given difference of level between that of the regulated lake and the water surface below the structure, and consist of 2,900 feet of fixed weir, together with 13 sluices 80 feet wide and 20 to 24 feet deep. The general designs and dimensions are shown on plate 85.

The sluice gates and counterweights for the proposed works are of the "Stoney type," with a slight modification, and are shown on plate 86, and the details of the suspending chains, roller system, and hoisting gear on plate 87.

Particular attention is called to the design for suspending chains, designed by Mr. S. H. Woodard, by which the effect of the immersion of the gate is eliminated, making the resistance to be overcome by the hoisting gear practically that due to friction and to the inertia of the moving parts.

The operation of the gates will require two men for each sluice, and the entire system could probably be opened in about forty-five minutes.

The piers for sluice gates can be constructed in one season, and the superstructure, gates, and fixed weirs during the second season after commencement of work.

The installation of regulating works will necessitate the construction of a lock for passing vessels from Lake Erie to ports on the Niagara River. Such a lock will, however, be a necessity with any project which provides for the same depth of channel for Tonawanda as for Lake Erie harbors, and very likely will be required with whatever

plan of improvement that may be adopted for Lake Erie harbors and waterways.

The heavy current in the head of Niagara River makes navigation of the river difficult and dangerous, but below the gorge the river is broad and deep, with a current of only about 2 miles per hour.

A canal for passing vessels around the rapids will avoid excessive currents for all stages of the river and secure safe navigation between the lake and ports on the Niagara River.

*Estimate of cost of regulating works in place.*

| | |
|---|---|
| Cribwork: | |
| Material for 6 cofferdams— | |
| 792 M feet B. M. white pine, at $35 per M | $27,720 |
| 147,600 pounds bolts and rods, at 3 cents | 4,428 |
| Towing and pumping, 14 cofferdams | 14,000 |
| Piers: | |
| Material in 14 piers— | |
| 1,671 cubic yards cut granite, at $46 | 76,866 |
| 601 cubic yards cut limestone, at $25 | 15,025 |
| 558 cubic yards paving block, at $20 | 11,160 |
| 3,393 cubic yards concrete, at $6 | 20,358 |
| 141,810 pounds cast-steel quoins, at 8 cents | 11,344 |
| 95,200 pounds old rails in concrete, at 1 cent | 952 |
| 14,140 pounds anchor bolts, at 4 cents | 565 |
| Sills: | |
| Material in 13 sills— | |
| 395 cubic yards concrete, at $10 | 3,950 |
| 71,610 pounds plates and bolts, at 5 cents | 3,580 |
| 57,700 pounds structural steel in one caisson, at 5 cents | 2,885 |
| Plant, and operating | 20,000 |
| Gates: | |
| Material in 13 gates— | |
| 2,523,760 pounds structural steel, at 5 cents | 126,188 |
| 107,780 pounds cast steel, at 6 cents | 6,467 |
| Counterweights: | |
| Material in 13 counterweights— | |
| 539,500 pounds structural steel, at 5 cents | 26,975 |
| 1,954,190 pounds cast-iron weights, at 1.5 cents | 29,313 |
| Chains: | |
| Material for 26 chains, 233,000 pounds steel, at 11 cents | 25,630 |
| Superstructure: | |
| 1,090,200 pounds structural steel, at 5 cents | 54,510 |
| 38 M feet B. M. flooring, at $30 per M | 1,140 |
| Hoisting gear: | |
| Material for 26 machines— | |
| 248,650 pounds gears, sheaves, etc., at 8 cents | 19,892 |
| 43,860 pounds shafting, at 4 cents | 1,754 |
| Roller trains: | |
| Material for 26 trains— | |
| 79,380 pounds rollers, at 10 cents | 7,938 |
| 57,940 pounds structural steel, at 5 cents | 2,897 |
| 8,100 pounds cast steel, at 6 cents | 486 |

| | |
|---|---|
| Submerged weir: | |
| 1,700 linear feet of weir, at $55 | $93,500 |
| 15,800 cubic yards rock excavation on reef, at $3 | 47,400 |
| Engineering and superintendence | 75,000 |
| Contingencies | 65,000 |
| Total | 796,923 |

*Estimate for 17-foot channel and lock 600 by 60 by 21 feet between Lake Erie and Niagara River below the gorge.*

| | |
|---|---|
| Excavation in lake, 600 feet wide, rock, 215,750 cubic yards, at $3 | $647,250 |
| Excavation in canal, 240 feet wide: | |
| Rock, 114,250 cubic yards, at $2 | 228,500 |
| Earth, 264,280 cubic yards, at 15 cents | 39,642 |
| Excavation at lock: | |
| Earth, 55,750 cubic yards, at 15 cents | 8,363 |
| Rock (dry), 49,650 cubic yards, at 80 cents | 39,720 |
| Retaining wall and crib: | |
| Masonry, 111,800 cubic yards, at $6 | 670,800 |
| Timber, 885,800 feet B. M., at $25 per M | 22,145 |
| Drift bolts, 79,670 pounds, at 3 cents | 2,390 |
| Stone filling, 10,210 cubic yards, at 50 cents | 5,105 |
| Lock: | |
| Concrete, 72,500 cubic yards, at $6 | 435,000 |
| Granite quoins, 190 cubic yards, at $55 | 10,450 |
| Cut stone, 480 cubic yards, at $25 | 12,000 |
| Brick lining, 1,200 cubic yards, at $12 | 14,400 |
| Gates, 1,310,000 pounds, at 5 cents | 65,500 |
| Steel castings, 63,200 pounds, at 6 cents | 3,792 |
| Pins and pivots, 10,200 pounds, at 10 cents | 1,020 |
| Anchor bars, 20,800 pounds, at 5 cents | 1,040 |
| Bronze bushings, 2,800 pounds, at 40 cents | 1,120 |
| Drift bolts, 63,000 pounds, at 3 cents | 1,890 |
| Oak timber, 36,000 feet B. M., at $50 per M | 1,800 |
| Operating plant | 75,000 |
| Contingencies | 100,000 |
| Total | 2,386,927 |

If a ship canal should be built from Lake Erie to Lake Ontario the channel would be made 21 feet or more in depth, and would be needed whether the regulating works were constructed or not.

The above estimate is based on a channel 17 feet deep, with a lock with 21 feet on miter sills, which will allow the improvement to a depth of 21 feet without change of structure.

## BENEFITS TO BE DERIVED.

If regulating works for controlling the level of Lake Erie should be constructed, the harbor and waterways of the lake will be improved in depth the amount that the level of the lake is raised above the natural stage of lake with which compared, and since the plane of regution proposed will be about 3 feet higher than the usual stage of water

during the latter part of the season of navigation, when the heaviest traffic on the lake occurs, the resulting improvement to be expected may be fairly taken at that amount. The aggregate cost of the improvement of Lake Erie harbors has averaged about $1,000,000 for each foot of permanent improvement obtained, or approximately $3,000,000 for the resulting increase of depth which would be produced by properly constructed regulating works.

Whatever amount the low-water stage of Lake Erie may be raised, the resulting effect on the low-water levels of Lake St. Clair and of Lakes Huron and Michigan will be, respectively, about two-thirds and one-third of the change of stage on Lake Erie.

The channels of the Detroit and St. Clair rivers should be made 600 feet wide to be safe for the vast and rapidly increasing traffic of the waterways.

To construct a 21-foot channel for standard low water of the lakes, and 600 feet wide, will require the excavation of the following amount of material:

| Location. | Kind of material. | | |
|---|---|---|---|
| | Sand, clay, and gravel. | Sand, clay, and bowlders. | Rock. |
| | *Cubic yards.* | *Cu. yds.* | *Cu. yds.* |
| Lake Erie at mouth of the Detroit River | 596,000 | | |
| Detroit River | 923,000 | 360,000 | 474,000 |
| Lake St. Clair | 5,514,000 | | |
| St. Clair River | 614,000 | | |
| Foot of Lake Huron | 1,198,000 | | |
| Total | 8,845,000 | 360,000 | 474,000 |

With the surface of Lake Erie regulated at an elevation of 574.5 feet above tide water (0.5 foot below extreme high water of lake), the amount of excavation necessary for the construction of a similar channel with a constant depth for entire season of navigation will be:

| Location. | Kind of material. | | |
|---|---|---|---|
| | Sand, clay, and gravel. | Sand, clay, and bowlders. | Rock. |
| | *Cubic yards.* | *Cu. yds.* | *Cu. yds.* |
| Lake Erie at mouth of the Detroit River | | | |
| Detroit River | | 159,000 | 266,000 |
| Lake St. Clair | 2,113,000 | | |
| St. Clair River | 415,000 | | |
| Foot of Lake Huron | 830,000 | | |
| Total | 3,358,000 | 159,000 | 266,000 |
| Total excavation saved by regulation | 5,487,000 | 201,000 | 208,000 |

Assuming that sand, clay, and gravel in Lake Erie at mouth of the Detroit River and St. Clair River can be excavated for 9 cents per cubic yard, in Lake St. Clair for 15 cents, and at foot of Lake Huron for 30 cents; sand, clay, and bowlders for 40 cents, and rock $2.50,

the cost of constructing a 21-foot channel 600 feet wide from Lake Erie to Lake Huron would be about $1,375,000 less with level of Lake Erie regulated than under the present conditions, or a saving of $578,000 more than the regulating works will cost. In other words, the value of the improvement to the waterway from Lake Erie to Lake Huron would be more than the amount necessary to construct the works at the foot of Lake Erie, making whatever benefits that would result to the harbors and channels of the lake a direct balance to the credit of the project.

If a deep-waterway channel should ever be constructed through the head of Niagara River, a dam at the foot of the lake will be an absolute necessity. Otherwise the level of Lake Erie would be lowered to such an extent as to materially damage existing improvements, as any improvement of Horseshoe Reef or of the gorge at the head of Niagara River will have a decided effect on level of waterway above the improvement.

One of the chief requisites for economical transportation on the waterways is to have a constant depth through the shallow portions during the entire season of navigation, so that vessels constructed with reference to the expected future depth of channels and harbors will be able to carry full cargoes at all times.

Since vessels are generally constructed for utilizing the maximum depth of the improved channels, this desirable condition can only be secured by regulating the lake levels.

## INTERNATIONAL FEATURES.

Any system of regulating works that may be designed by which the level of the lake can be controlled will necessarily be partly in Canadian territory and subject to the approval of the Canadian government before it can be constructed. The stage at which the regulated level of lake should be fixed is also a matter of importance to both countries and would probably have to be settled by an agreement between the two Governments.

## SUMMARY.

Complete regulation of any lake level requires that the sum of the evaporation from the surface and the outflow shall at all times be approximately equal to the total supply, and since the evaporation from Lakes Michigan and Huron is of itself at times largely in excess of the supply a complete control of the level of those lakes is an impossibility. The reservoir capacity of the upper lakes is, however, sufficient to allow of considerable decrease of the extreme fluctuations of Lakes Michigan and Huron without injurious effects on the waterways.

The low-water level of Lakes Michigan and Huron has been lowered about 1 foot during the past thirteen years by the natural and artificial

deepening of the channels of the St. Clair and Detroit rivers, and since the indirect effect on Lake Huron will be about one-third of the amount that the low-water stage of lake Erie is raised the regulation of the latter lake at a plane 3 feet above ordinary low water will restore the limit of low water on Lakes Michigan and Huron to what it was previous to 1886 and diminish the fluctuations of those lakes about 1 foot.

The regulation of Lake Erie will not materially change the total annual discharge through the Niagara River and will only modify the distribution of flow about 5 per cent of the average discharge, and therefore can not materially affect the level of Lake Ontario and the St. Lawrence River.

At the stage of 574.5 feet above tide water—0.5 below extreme high water—the outflow from Lake Erie is approximately equal to the maximum known to supply the lake, and, if regulated at such stage, the level of the lake would be susceptible of complete control except as affected by the wind.

For a complete control of the levels at any lower stage an enlargement of the gorge at the head of Niagara River will be necessary, and whatever plane of regulation may be adopted will require international consideration.

The enlargement of the waterway through the Detroit and St. Clair rivers to a width of 600 feet is an urgent necessity, and the cost of such improvement will be diminished by the regulation of the lake levels an amount more than sufficient to construct the regulating works.

A fixed depth for the entire season of navigation through the shallow portions of the connecting waterways is very essential to the transportation interests, and can only be secured by the regulation of the lake levels.

The harbors and channels of Lake Erie will all be permanently improved an amount equal to the elevation of the adopted plane of regulation above ordinary low water of the lake, which unfortunately occurs at the season of heaviest traffic on the lake.

Respectfully submitted.

GEO. Y. WISNER.

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

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## APPENDIX NO. 7.

### NIAGARA RIVER DISCHARGE.

DETROIT, MICH., *August 15, 1899.*

GENTLEMEN: I have the honor to submit the following report on the discharge measurements made in the Niagara River at Buffalo, N. Y., between the dates September, 1897, and September, 1898.

From September, 1897, to December, 1897, the work was in charge of Assistant Engineer E. E. Haskell, to whom credit is due for the planning of the work and methods employed.

From July, 1898, to September, 1898, the work was in charge of Assistant Engineer F. C. Shenehon.

The writer has acted as subassistant engineer during field work on these dates, and at intervals between has been in charge of the computations for the discharge measurements.

Since September, 1898, the work of gauging the river has been continued by the United States Lake Survey, and through the courtesy of E. E. Haskell, United States assistant engineer in charge, and F. C. Shenehon, resident engineer, the Board has been furnished with some thirty-eight discharge measurements and considerable data as to river slopes.

## THE DISCHARGE SECTION.

The discharge section was located on the line of the guard rail on the north side of the International Bridge, about 3 miles below the head of the river. The location of the section and its relation to other parts of the river can be seen on the map, plates 14 and 84.

The bridge is a single-track railroad bridge, having a plank walk about 5 feet wide on each side of the track. This afforded a favorable opportunity for crossing the river quickly during discharge measurements and ease in reaching any station for work on vertical or transverse curves.

The bridge consists of nine spans, which were numbered from the American shore and have the following water widths:

TABLE No. 1.

| Span No. | Water width. | Width of pier. | Span No. | Water width. | Width of pier. |
|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | | *Feet.* | *Feet.* |
| 1 | 151.5 | ..... | 7 | 186.9 | 9.5 |
| 2 | 154.1 | 19.0 | 8 | 184.3 | 10.0 |
| 3 | 156.2 | [1]35.0 | 9 | 138.3 | 17.0 |
| 4 | 234.2 | 13.0 | | | |
| 5 | 235.8 | 13.0 | Total | 1,676.6 | 129.5 |
| 6 | 235.3 | 13.0 | | | |

[1] Pivot pier.

Total width of river=1,806 feet.

The piers have a batter on the sides of about 1:24, so that the water widths of the intermediate spans may be taken as constant. They have a length of about 35 feet, with a cut water on the upstream end, the downstream end being rectangular in form.

Eddies are produced by the piers to some extent, but they do not extend more than about 5 feet from the pier and in most cases the current remains practically linear and with about the same amount of fluctuations as near the middle of the span. It is thought that little error has been introduced from this source.

For the location of the stations on the discharge section the shorter spans, Nos. 1, 2, 3, 7, 8, and 9, were divided into eight equal parts and the longer spans, Nos. 4, 5, and 6, into twelve equal parts, thus making the distance between stations about 20 feet. These stations were marked on the guard rail of the bridge, each station being designated by the fractional eighth or twelfth it was from the end of the span. In addition to these stations sounding stations were established at points about 10 feet apart in each span.

The soundings were taken with a 41-pound cast-iron weight, attached to a sash chain, in the swift and deeper water and with a 25-pound lead in the shallower water. The depths in each case were measured from the guard rail, the elevations of the guard rail having been determined, as well as its elevation above the water surface for mean river stage.

The soundings were carefully taken on each set of stations independently, and any discrepancy shown by the plotting of the two sets was carefully gone over. From the soundings the cross section has been plotted and is shown in plate 88.

The bed of the river is formed of clay on the American shore and rock on the Canadian shore. No attempt was made to determine the character of the bed in the middle, but it is probable that it is of clay. The piers in the deeper water have been protected by heavy riprap, extending to within about 10 or 20 feet from the water surface.

### WATER GAUGES.

The water gauges used were of the box-with-float type. These gauges consist of a pine box made of seven-eighths inch material, 7 by 7 inches in cross section and about 7 feet long, having a closed bottom and removable cover. These boxes are placed vertical, with about half length under water. On the face of the box and under water three one-fourth inch holes are bored, being spaced about 1 foot apart. These holes allow the inflow and outflow of water and secure a still-water surface. Floating in the box is a 2-quart bottle with a 7-foot staff wedged into it and graduated to feet, tenths, and hundredths. This staff extends up through a hole in the cover, and where it cuts the top of this cover is called the index point or reading point. The sensitiveness of the gauge can be adjusted by opening or closing one or two of the one-fourth inch holes. The zero on the staff is marked at 7 feet from the water surface or float line, with reading increasing downward from this point, the object being to have the increasing readings on the staff correspond with a water rise in the water surface. Having the elevation of the index point and reading on the staff, the elevation of the water surface can be readily determined.

In September, 1897, eight of these gauges were established along the American shore between the lake and the discharge section for

the purpose of determining the slope of the river in the various reaches. The gauges were numbered from 1 to 8 and their locations are shown on the map (plate 14). Simultaneous readings were made on each of the gauges at intervals of ten minutes from 7.30 a. m. to 5 p. m.

Gauge No. 1, located in Erie Basin, was intended to give the level of Lake Erie. This gauge is located near the Government standard gauge, a staff gauge, which was read by the United States engineers at Buffalo between 1887 and 1897.

In July, 1898, additional box-with-float gauges were established as follows: 1 L, 2 L, 2 A, 2 B, and 2 C. (See plate 14.)

Gauges 1 L and 2 L are the lake gauges, replacing gauge No. 1, which had not proven satisfactory. These gauges, 1 L and 2 L, are located, respectively, on the American shore and Canadian shore, each about 2½ miles from the head of the river. They are placed well outside any effect from the river current, but yet not so far as to introduce an error from slope in lake surface resulting from wind.

Gauges 2 A and 2 B are between gauges Nos. 2 and 3; gauge 2 C is on the Canadian shore opposite gauge No. 2. During July and August the 13 gauges were read at ten-minute intervals throughout the day.

## OUTFIT FOR CURRENT OBSERVATIONS.

*Reel.*—The meter was handled by means of a reel mounted on two wheels and provided with suitable handle bars, so that it could be easily moved from one point to another. The reel has a drum about 1 foot long and exactly 5 feet in circumference, measured on the center line of the three-eighths inch steel wire cable which winds on it. The circumference of the drum is divided into feet and tenths of feet, so that any required length of cable can easily be paid out. The drum is turned by suitable hand cranks connected to the drum by gearing at the ratio of about 6 to 1, so that weights of from 200 to 300 pounds can be easily handled. From the drum the cable leads over a guiding sheave placed so that the cable leading to the water will clear the guard rail of the bridge and pass between the eye bars.

*Current meters and recording device.*—The current meters used were of the Haskell form, which belong to the screw or propeller type, and are electric recording. The battery to generate the electric current is carried in a box on the reel. From the battery the current passes through the electric magnet of the recorder, then to an insulated wire on the interior of the cable by means of a spring pressing against a brass ring on one end of the drum and to which the insulated wire is connected. In the meter wheel and revolving with it are two semi-disks, one of india rubber and one of platinum. The insulated wire is connected to a contact spring, which presses alternately against the platinum and india rubber as the meter wheel revolves. The return circuit is made by means of the metal of the cable. In this way the

circuit is alternately made and broken at each revolution of the meter wheel, and then, by means of the electro-magnet, the revolutions are recorded at the surface. A stop watch is also included in the circuit and so arranged that the starting of the stop watch completes the circuit and stopping the watch breaks the circuit.

The following is a list and description of the current meters used:

1. Current meter, Form E, No. 1, high and low pitch wheels. This meter has a length of 16 inches; diameter of wheel, 4 inches; weight of meter, $2\frac{3}{4}$ pounds; weight of lead weight, 20 pounds.

2. Direction current meter, Form A, No. 12, low-pitch wheel. Length of meter, 36 inches; diameter of wheel, $7\frac{1}{2}$ inches; weight of meter, 30 pounds; weight of lead weight, 65 pounds. The wheel of this meter is extremely sensitive, and will register accurately velocities from 0.25 foot per second to 10 feet per second. In the center of the meter is a chamber about 12 inches long filled with oil. In this chamber a magnetic needle is suspended and is free to assume the magnetic meridian. By means of a make-and-break circuit in the chamber and a corresponding make-and-break circuit on the surface the direction of the current can be measured with a probable error of about $\pm$ 2°. For a more complete description of the direction part of this meter see page 304.

3. Current meter, Form B. The discharge measurements made by the United States Lake Survey and furnished to the Board were all taken with a Haskell current meter, Form B. This meter only differs from the direction meter A in the omission of the direction part. It is a very reliable meter and well adapted to work in swift currents.

### RATING OF CURRENT METERS.

The field observations of October, November, and December, 1897, were made with meters E, No. 1, high and low pitch wheels, and with direction meter A, No. 12.

These meters were rated at the City Park, Buffalo, N. Y., October 23–27, 1897.

A small catamaran was rigged with the meter about 5 feet in front of the boat and $2\frac{1}{2}$ feet under the water. A No. 15 steel wire, on which a length of base of 300 feet was accurately laid off, was stretched across a suitable part of the lake where the water was at least 5 feet deep. This wire was floated by small blocks of wood. A five-eighths-inch rope was then stretched parallel to the base and about 5 feet from it. Three men astride this rope then pulled the catamaran from one end of the base to the other at as uniform a speed as possible. The electric recorder and stop watch were started at the instant of passing the zero mark of the base and stopped at the instant of passing the 300-foot mark. The observation was repeated with the boat going in the opposite direction, so as to be able to eliminate any effect from current if it should exist. From the revolutions of meter wheel,

time interval, and length of base the quantities, revolutions per second, and velocity of boat in feet per second are obtained.

Before any rigid reductions of the observations were made these points were platted on cross-section paper, using velocity in feet per second as ordinates and revolutions per second as abscissæ. Should any point differ from the mean line by an amount which showed that an error had been introduced from some source, it was rejected. The remaining observations were treated by the rigid method of least squares. If a straight line seemed to fit the platted points, the linear form $y=a+bx$ was assumed. If there was an indication that a curve would be preferable, the form of the parabola, with axis vertical, $y=a+bx+cx^2$ was assumed. An observation equation was then formed from each of the observations, $x$ and $y$ being the observed quantities and $a$, $b$, and $c$ the unknowns. The normal equations are then written from these observation equations and solved for the quantities $a$, $b$, and $c$.

The following table shows the reductions of the rating observations made at City Park, Buffalo, N. Y., October 23–27, 1897:

| Current meter. | Number of observations used. | Number of observations rejected. | Rating equation. | Range in observation velocity. | Probable error of single observation. |
|---|---|---|---|---|---|
| Form E, No. 1: | | | | *Foot-secs.* | *Foot-secs.* |
| Low-pitch wheel | 26 | 3 | $y=+0.334+0.894x+0.067x^2$ | 0.50—3.70 | +0.060 |
| High-pitch wheel | 28 | 1 | $y=+0.151+1.896x+0.061x^2$ | 0.80—6.20 | +0.072 |
| Direction meter A, No. 12. | 32 | 2 | $y=0.216+1.217x$ | 0.40—6.30 | +0.048 |

Meters E, low and high pitch wheels, were used during the month of October, 1897, previous to the arrival of direction meter A, No. 12.

Meter E, low-pitch wheel, is intended for measuring low velocities, so the range of velocities for rating was not carried higher than about 3.70 feet per second. It has been used for measuring velocities in the vertical and transverse curves in spans Nos. 1 and 2, the velocity not exceeding about 3 feet per second.

The probable error of a single observation from the rating observations is $\pm 0.060$ foot per second.

Meter E, high-pitch wheel, will measure high velocities, but on account of its light weight it could not be used in the swift currents, as it would be carried too far below the discharge section. It has been used in measuring velocities in the vertical and transverse curves in spans Nos. 1, 2, 8, and 9, the velocity not exceeding about 5 feet per second. The probable error of a single observation is $\pm 0.072$ foot per second. Direction meter A, No. 12, is a very reliable meter, and is suited to both high and low velocities. It has been used in the greater part of the work in measuring velocities for vertical curves, transverse curves, and discharge measurements. The probable error of a single observation is $\pm 0.048$ foot per second.

The field observations of July and August, 1898, were made for the most part with meter A, No. 12, a few being made with meter E, high-pitch wheel, in spans Nos. 1, 2, 8, and 9. For this work careful reratings of these two meters were made in the city reservoir, Buffalo, N. Y. The reservoir is rectangular in shape, about 400 feet by 600 feet, with paved sides and bottom, the sides having a slope of 1 on 2. The reservoir is in direct connection with the water mains, but is only drawn from in case of a sudden draft, as for fire purposes. An automatic gauge is maintained, so that any lowering of the surface and resulting development of currents from this source would be shown. Slight currents were developed by the wind, but when it was calm the water was perfectly quiet.

A 300-foot base was selected parallel to one side, where the water was about 6 feet deep. This base was marked on a No. 15 steel wire and floated in position by wooden blocks. A rowboat was arranged so as to carry the meter about 5 feet in front of the boat and 3 feet under water. The observer sat in the bow of the boat near the recording apparatus and was able to see the meter at all times. Another man sat in the stern of the boat and kept it parallel to the base. The boat was pulled back and forth along the base by means of suitable lines leading to the shore, a long pole being used at the bow to keep the boat in the required position. In order to make the movement of the boat uniform a base was laid out on shore parallel to the base on the water and with marks at each 50 feet.

The intervals of time in going over the first 50 feet were noted, and at the successive equal time intervals some sign was given, so that the speed of the boat could be increased or decreased accordingly.

The observations were reduced by the rigid method of least squares, as already described. The results of the ratings on these two meters are shown below.

*Meter E, high-pitch wheel, August 26, 1898.*—It was found that the observations having a velocity exceeding $1\frac{1}{2}$ feet per second plotted in a straight line. Accordingly a linear equation has been deduced from the observations above this point, while below a curve has been sketched in.

Number of observations = 30.
Number of observations, velocity below $1\frac{1}{2}$ feet per second = 3.
Number of observations used in reductions = 27.
Rating equation $y = -0.026+2.064x$.
Range in observed velocity = (0.60—7.30) feet per second.
Probable error of a single observation = $\pm 0.043$ feet per second.

*Direction meter A No. 12, July 15, 1898.*—In this rating a current, from wind, of about 0.15 foot per second and very nearly constant, was found to exist parallel to the base. The observations plotted in two very good, straight lines, one for each direction of movement of the boat. The rating equation was determined by two methods.

1. The equations of the two lines were obtained by the method of least squares, by treating the observations from each direction inde-

pendently. A line bisecting the angle between these two lines was taken as the rating line. This method assumes the current to be constant or varying uniformly during the rating observations.

2. The observations were divided into pairs, each pair consisting of consecutive observations, one in each direction. The mean of the velocities and revolutions per second of each pair are taken as a single observation, and from these the rating line obtained by the method of least squares. In this way the current is only assumed to be constant during two consecutive observations.

The rating lines obtained by the two methods give velocities agreeing within about 0.01 foot per second. The second method is considered the better one of the two, and is the one adopted.

The results of the reductions are shown below:

Number of pairs of observations = 17.
Rating equation $y = +0.116 + 1.208x$.
Range in observed velocities, 0.70 to 8.20 feet per second.
Probable error of a single observation $= \pm 0.027$ foot per second.

This meter had been returned to the manufacturer during the winter of 1898, and the blades of the wheel had been reshaped, so the above rating equation is slightly different from the one obtained in 1897.

*Summary and comparison of meter ratings.*

METER E NO. 1, LOW-PITCH WHEEL.

| Place and date. | Rating equation. | Velocity (feet per second corresponding to revolutions per second). | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0.0 foot-second. | 0.5 foot-second. | 1.0 foot-second. | 1.5 foot-seconds. | 2.0 foot-seconds. | 2.5 foot-seconds. | 3.0 foot-seconds. |
| City Park, Buffalo, N. Y., October, 1897. | $y = +0.334 + 0.894x + 0.067x^2$ .. | 0.33 | 0.80 | 1.30 | 1.83 | 2.39 | 2.99 | 3.62 |
| Sault Ste. Marie, Mich., March, 1896.[1] | $y = +0.378 + 0.813x + 0.083x^2$ .. | .38 | 0.81 | 1.27 | 1.79 | 2.34 | 2.93 | 3.56 |

[1] See report of E. E. Haskell, United States assistant engineer, on discharge of the St. Marys River, report of Chief of Engineers 1897, page 4092.

This meter has been used in measuring velocities, in vertical and transverse curves, the velocity not exceeding 3 feet per second.

METER E NO. 1, HIGH-PITCH WHEEL.

| Place and date. | Rating equation. | Velocity (feet per second corresponding to revolutions per second). | | | | | |
|---|---|---|---|---|---|---|---|
| | | 0.0 foot-second. | 0.5 foot-second. | 1.0 foot-second. | 1.5 foot-seconds. | 2.0 foot-seconds. | 2.5 foot-seconds. |
| City Park, Buffalo, N. Y. October, 1897. | $y = 0.15 + 1.896x + 0.061x^2$ ..... | 0.50 | 1.11 | 2.11 | 3.13 | 4.19 | 5.27 |
| City reservoir, Buffalo, N. Y., August, 1898 | $y = -0.026 + 2.064x$ ..... | .50 | 1.06 | 2.04 | 3.07 | 4.10 | 5.14 |

This meter has been used in measuring velocities in vertical and transverse curves, the velocity not exceeding 5.25 feet per second. The rating lines for this meter for velocities below 1½ feet per second have been sketched in by eye from plotted observations, so the rating equations given do not apply below this limit.

DIRECTION METER A NO. 12.

| Place and date. | Rating equation. | Velocity (feet per second corresponding to revolutions per second). | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 0.0 foot-second. | 1.0 foot-second. | 2.0 foot-seconds. | 3.0 foot-seconds. | 4.0 foot-seconds. | 5.0 foot-seconds. | 6.0 foot-seconds. | 7.0 foot-seconds. |
| City Park, Buffalo, N.Y., October, 1897. | $y=0.216+1.217x$ | 0.22 | 1.43 | 2.65 | 3.87 | 5.08 | 6.30 | 7.52 | 8.73 |
| City reservoir, Buffalo, N. Y., July, 1898. | $y=0.116+1.208x$ | .12 | 1.32 | 2.53 | 3.74 | 4.95 | 6.16 | 7.37 | 8.57 |

In making the comparison of the ratings of this meter it should be remembered that the meter wheel had been altered between the two sets of observations. It has been used in the more important vertical and transverse curves and in the discharge measurements. The maximum velocity was about 8 feet per second. In all cases the field observations with each meter have been reduced by the rating equation determined during the corresponding year.

METER OBSERVATIONS.

As already stated, the shorter spans were divided into 8 equal parts and the longer spans into 12 equal parts, the stations being designated by the fractional eighths or twelfths from one end of the span.

*Observations for discharge.*—The general method of proceeding in taking a discharge measurement is to measure the velocity at some percentage of the depth at stations on the cross section, passing from one to another as rapidly as possible. The stations were called meter stations, and were about 80 feet apart. In the short spans they were located at the stations $\frac{2}{8}$ and $\frac{6}{8}$, and in the longer spans at the stations $\frac{2}{12}$, $\frac{6}{12}$, and $\frac{10}{12}$. In this way each observation represented a width of river corresponding to one-half or one-third of the span, and was located in the middle of that part. As the general shape of the cross-section of each span is somewhat triangular, in order to reduce the observed velocity to mean velocity it was necessary to have a system of vertical curves, showing the variation of the velocity in a vertical plane, and a system of transverse curves, showing the variation of velocity as we cross the river. The combination of the two sets of curves gives a coefficient which, multiplied by the observed velocity, gives mean velocity. This mean velocity, multiplied by the area of the corresponding one-half or one-third, gives discharge.

All of the observations for discharge were made at the $\frac{3}{10}$-depth point. This ratio $\frac{3}{10}$ depth was adopted, as it seemed the one best

suited to the conditions. The bridge being about 22 feet above the water surface, and the current swift, it was impossible to prevent the meter from being carried downstream. The form of the vertical curve at the point $\frac{3}{10}$ of the depth is very nearly vertical, so that a slight error in the location of the meter from the $\frac{3}{10}$ position would not have much effect on the velocity. The $\frac{3}{10}$-depth point spoken of is not located exactly at a distance below the surface of $\frac{3}{10}$ depth of water, but is determined as follows: Observations at the surface must be taken with the meter wheel 1 foot below the water surface, so as to have the lashing of the cable to the meter immersed. Observations at the bottom must have the lead weight slightly clear of the bottom. This would place the meter wheel $1\frac{1}{2}$ feet above the bottom.

The intervening space (depth $-2\frac{1}{2}$ feet) is divided into ten equal parts, and the points of division are spoken of as the respective tenths of the depth. From this it is seen that the $\frac{3}{10}$-depth point is located at a distance below the surface of $\frac{3}{10}(D-2\frac{1}{2})+1$, where D represents depth of water in feet.

This expression was evaluated for each station, using the depths corresponding to an approximate mean river stage. The correction on account of change in stage will be $\pm \frac{3}{10} \times$ (change of stage in feet).

In the swifter current of about 6 feet per second and with the meter at $\frac{3}{10}$ depth, it will be carried downstream from 12 to 14 feet, the meter cable making an angle from the vertical of about 25°; so that in order to place the meter at the $\frac{3}{10}$-depth point a relation must be obtained between the vertical distance and the slant distance below the water surface. To do this, observations were made at each station for the angle of the cable from the vertical when the meter was approximately at the $\frac{3}{10}$-depth point and the river about at mean stage. This angle was measured by means of a board having a graduated quadrant, and being held alongside of the cable at a point just below the lower chord eye bars of the bridge, the cable being free below this point.

The lower chord eyebars of the bridge are approximately 22 feet above the water surface when the river is at mean stage. Then, starting with the meter wheel at the water surface, the amount of cable to pay out to place the meter at the $\frac{3}{10}$-depth point is given by the equations:

$$\text{Amount of cable to pay out to place meter at } \tfrac{3}{10} \text{ depth} = L = 22(\sec x - 1) + [\tfrac{3}{10}(D - 2\tfrac{1}{2}) + 1] \sec x;$$

where $x$ represents the angle of the cable from the vertical, and D the depth of water in feet. This method assumes that the cable continues in a straight line under the water surface instead of a slight curve.

In order to determine the error from this assumption, and others of a like nature—explained later—the curve of the cable under water

and under different conditions has been traced graphically This has been done as follows:

The pressure of the current on the meter was determined by lowering the meter wheel 1 foot under water and measuring the vertical angle $x$ of the cable; then the pressure on the meter equals weight under water multiplied by tan $x$. The velocity was also observed, and from a number of such observations a very good curve showing relation of velocity and pressure on meter was obtained. After each of the observations for pressure on meter was completed an additional 5 feet of cable was paid out and the vertical angle of the cable again measured. The tangent of this angle multiplied by weight under water gives the pressure on the meter and 5 feet of cable. The law for the pressure on the meter being known, the pressure on the 5 feet of cable is easily computed, and from a number of such observations the law for the pressure on the cable obtained.

Then, starting with the known weight of meter and measured or assumed velocities, we can trace graphically the curve of the cable under water. A check on the graphical work is obtained by comparing the vertical angle at the surface with the measured vertical angle.

At mean river stage the error from assuming the cable to continue straight under the water surface, and in placing the meter at the $\frac{3}{10}$ depth by the formula given for L, amounts to about 0.4 foot under the most unfavorable conditions, the meter being too low by this amount. The vertical depths and corresponding values of L were worked out and tabulated for each of the stations.

The correction to L on account of change of stage, assuming $x$ to remain constant and taking $a$ as representing the change of stage in feet, would be:

$$\text{Correction to L} = \mp a(\sec x - 1) \pm \tfrac{3}{10} a \sec x,$$

when the upper signs are used for a high stage and the lower signs for a low stage.

As the limiting value of $a$ was about $1\frac{1}{2}$ feet and of $x$ about 25°, this correction has been taken as $\pm \frac{3}{10} a$.

In order to determine the error from assuming $x$ to remain constant at all stages, and of the cable to continue straight under the water surface, graphical analyses have been made where extreme conditions have been assumed. The following results were obtained:

1. The river being $1\frac{1}{2}$ feet above mean stage and the velocity about 8 feet per second, according to the formula as used, the meter would be 1.25 feet above the $\frac{3}{10}$ depth.

2. The river being $1\frac{1}{2}$ feet below mean stage and the velocity about 5 feet per second, according to the formula as used, the meter would be 1.25 feet below the $\frac{3}{10}$-depth point.

The depth of water at the point considered is about 53 feet, so the variation from the $\frac{3}{10}$-depth point amounted to only about 2 per cent of the depth. It will be seen later that observations at extreme high

and low stages have not been used in the final reductions. For the observations used it is probable that the variation from the $\frac{3}{10}$ depth has not exceeded 0.75 foot.

In taking an observation for discharge, the meter is placed at the $\frac{3}{10}$ depth, according to the method prescribed. The stop watch and recorder are then started and allowed to continue for an interval of 100 seconds, and the number of revolutions made are noted. In this way all the meter stations are occupied consecutively from one shore to the other and as rapidly as possible. The length of time occupied in taking a complete discharge measurement was usually about two hours.

*Observations for vertical curves.*—Vertical curves were taken at each of the meter stations or stations occupied in a discharge measurement. In addition to these, a few curves were taken at each of the $\frac{4}{8}$ stations of the short spans. In the vertical curves the velocity was measured at each tenth of the depth, the meter being placed at these points in the following manner: Starting with the bottom of the lead weight at the water surface, the meter was lowered until the lead weight touched the bottom, a record being kept of the amount of cable paid out. This length, less $2\frac{1}{2}$ feet, was divided into ten equal parts, and each part taken as the amount of cable to take up in order to raise the meter $\frac{1}{10}$ part of the depth.

The first observation was made with the lead weight just clearing the bottom. The other observations were then taken consecutively at each tenth of the depth, from the bottom upward, the last observation, called the surface, being with center of the meter wheel 1 foot below the surface.

In order to prevent the meter from being carried too far downstream, sleeve weights of cast iron were attached to the cable. These sleeve weights were $2\frac{5}{8}$ inches in diameter, 18 inches long, and weighed 20 pounds.

In spans Nos. 4, 5, and 6, five of these sleeve weights were used, the lower one being attached 10 feet above the meter wheel and the others directly above, with spaces of 6 inches between.

A graphical analysis of the curve of the cable, showing the position of the meter at the tenths of the depth, has been made. The result has shown that this method of placing the meter has been amply close, the largest variation from the true position being at the $\frac{6}{10}$ depth, where the meter was about 1 foot too high.

At each observation the time interval was taken as 60 seconds; so the time occupied in taking a complete vertical curve was about 15 minutes. It was the practice to take about 3 complete vertical curves at one station before moving to the next. From 8 to 10 vertical curves were taken at each of the meter stations to form a mean vertical curve.

*Observations for transverse curves.*—In observing for transverse curves the meter is placed at the $\frac{3}{10}$ depth point in the same manner

as in observing for a discharge. The observations were made in regular order at all stations, including those at the ends of the spans. From 6 to 10 transverse curves were taken in each span to form a mean transverse curve. The length of time required to observe a transverse curve of one span was from 30 to 45 minutes.

*Observations for direction of current.*—Observations for direction of the current were taken at each observation in connection with about 5 complete transverse curves and at all the meter stations in the case of about 10 discharge measurements. The observation consists in recording the azimuth of the direction in which the current flows by means of the direction part of the meter. The meter was given about one minute to assume a settled position. Then the make-and-break circuits, one in the meter chamber and one on the surface, were started. The one on the surface reproduces by an index the arc, at any instant, through which a traveling point in the meter chamber has moved from the plane in which the meter stands. On reaching the plane of the magnetic needle the circuit is finally closed by the moving point striking against the lug on the needle. The reading of the index is then the azimuth of the direction of the current.

The direction was practically constant between the $\frac{2}{8}$ and $\frac{6}{8}$ stations of the short spans and between the $\frac{2}{12}$ and $\frac{10}{12}$ stations of the long spans. Next to the piers the direction was somewhat variable, and the meter would swing through an angle of 10° or 15°. In such cases the mean of several determinations was taken as the direction.

*Observations for the mean direction of flow of the river.*—In order to determine the mean direction of flow of the river three discharge measurements were selected, in which the direction of the current for each of the meter stations had been observed, and when the direction part of the meter had worked very satisfactorily. This gave three sets of twenty-one readings each, and at distances of about 80 feet apart. The maximum range in direction of the current in any one of the sets was about 10°. The mean of the three sets gave an azimuth of 187° from the magnetic south as the mean direction of flow of the river. The variation of the mean direction at any point from the mean direction of the whole river would not exceed 2° or 3°.

*Observations for the direction of the normal to the bridge or to the line of the discharge section.*—In these observations the meter was placed on the ground and lined parallel with the cross ties. About 20 observations were made at each end of the bridge. The mean of 40 observations give the azimuth of the normal to the discharge section at 185.1°.

From this it will be seen that the mean direction of flow of the river is 2° to the right from the normal to the discharge section, and that the mean direction of flow and the discharge section are practically at right angles.

In the case of the individual discharge measurements no corrections were necessary to the measured velocities on account of the

direction of the current. In the case of the transverse curves, the velocities at stations near the piers have been corrected by multiplying them by the cosine of the angle from the mean direction of flow of the river.

REDUCTION OF OBSERVATIONS.

*Area of cross section.*—The partial areas for the one-half and one-third part of span were computed for each tenth of a foot elevation of water service at the discharge section, and covering the range of the discharge measurements. The following table gives these partial areas for an elevation of 567 feet above mean tide at New York:

TABLE NO. 2.—*Area of cross section at bridge.*

[Elevation of water surface=567.]

| Span No. | East half or third. | Middle third. | West half or third. | Total. |
|---|---|---|---|---|
| | *Sq. feet.* | *Sq. feet.* | *Sq. feet.* | *Sq. feet.* |
| 1 | 495 | ---------- | 761 | 1,256 |
| 2 | 807 | ---------- | 901 | 1,708 |
| 3 | 2,058 | ---------- | 2,120 | 4,178 |
| 4 | 2,718 | 3,985 | 3,199 | 9,902 |
| 5 | 3,198 | 3,100 | 2,743 | 9,041 |
| 6 | 2,522 | 2,735 | 1,552 | 6,809 |
| 7 | 1,825 | ---------- | 1,824 | 3,649 |
| 8 | 1,363 | ---------- | 1,235 | 2,598 |
| 9 | 378 | ---------- | 110 | 488 |

Total area, 39,629.

*Vertical curves and transverse curves.*—A mean vertical curve is formed from the 8 or 10 individual curves by averaging the velocities of each tenth of the depth. This curve is then plotted by using depths and velocities as coordinates. The average velocity is obtained by dividing the area by depth of water. The ratio of this average velocity to the average of the observed velocities at $\frac{3}{10}$ depth is called the coefficient for the vertical curves at this station. Then observed velocity at $\frac{3}{10}$ depth multiplied by coefficient gives average velocity. This coefficient strictly only holds within the range of river stage covered by the individual vertical curves. In all discharge measurements to date it has been assumed that for moderate changes of stage the coefficient will remain constant. The observations we have, while not proving or disproving the assumption, yet tend greatly to strengthen it. If the velocities in a vertical plane vary from some cause it is noticeable that at points located by percentages of the depth, the velocities will vary in the same proportion. The change of form of the vertical curve is shown by the accompanying sketch (fig. 1).

The full line *a b c d* represents the original vertical curve.

First. Assume the velocities at percentages of the depth, as at 10th, to remain constant while the depth increases, the curve taking the form *a' b' c d*. In this change the area and depth will increase in the same ratio, so the average velocity and coefficient will remain the constant.

Second. Assume the depth to remain constant and all the velocities to increase in the same proportion, the curve taking the form $a'\ b''\ c'\ d$. In this change the average velocity will increase in the same proportion as the individual velocities, so the coefficient will remain constant. Then we have the following assumption in regard to vertical curves:

In the vertical plane, velocities, located by percentages of depth, vary in the same proportion, and as a result the coefficient for vertical curves will remain constant.

As the mean vertical curve represents a certain width of cross-section, coefficient for vertical curve remaining constant, we can trace out the form of the vertical curve at any point in this width by the method indicated in fig. 1, when the average velocity and depth at the point are known.

As a further relation between vertical curves in the different vertical planes, we must also assume that they will be changed according to the same law, i. e., coefficient for vertical curves remaining constant, velocities located by percentages of the depth will all vary in the same proportion.

The following table gives the list of transverse curves, vertical curves, and coefficients for vertical curves:

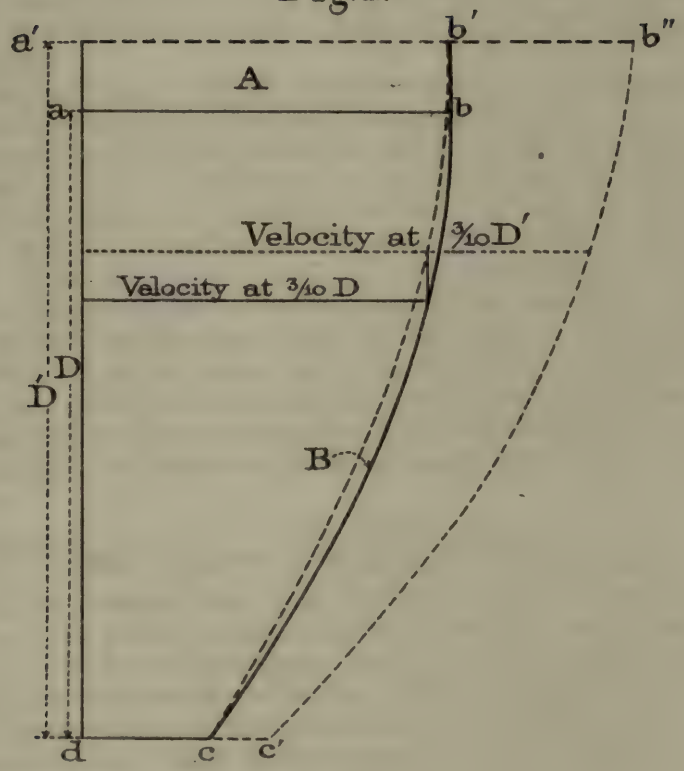
TABLE NO. 3.—*List of transverse curves, vertical curves, and coefficients for vertical curves.*

| Transverse curves. | | Vertical curves. | | | Transverse curves. | | Vertical curves. | | |
|---|---|---|---|---|---|---|---|---|---|
| Span No. | Number of curves observed. | Station. | Number of curves observed. | Coefficient for vertical curves. | Span No. | Number of curves observed. | Station. | Number of curves observed. | Coefficient for vertical curves. |
| 1 | 7 | $\frac{3}{12}$ | 10 | 0.89 | 6 | 10 | $\frac{3}{12}$ | 13 | 0.88 |
| | | $\frac{4}{12}$ | 11 | 0.88 | | | $\frac{4}{12}$ | 1 | 0.85 |
| 2 | 7 | $\frac{5}{12}$ | 13 | 0.90 | | | $\frac{5}{12}$ | 8 | 0.90 |
| | | $\frac{6}{12}$ | 10 | 0.94 | | | $\frac{6}{12}$ | 5 | 0.92 |
| | | $\frac{7}{12}$ | 13 | 0.96 | | | $\frac{7}{12}$ | 8 | 0.80 |
| 3 | 9 | $\frac{2}{12}$ | 6 | 0.86 | 7 | 10 | $\frac{2}{12}$ | 6 | 0.84 |
| | | $\frac{3}{12}$ | 4 | 0.91 | | | $\frac{3}{12}$ | 3 | 0.93 |
| | | $\frac{4}{12}$ | 6 | 0.87 | | | $\frac{4}{12}$ | 6 | 0.91 |
| 4 | 8 | $\frac{5}{12}$ | 8 | 0.90 | 8 | 7 | $\frac{5}{12}$ | 18 | 0.95 |
| | | $\frac{6}{12}$ | 10 | 0.92 | | | $\frac{6}{12}$ | 10 | 0.94 |
| | | $\frac{7}{12}$ | 11 | 0.93 | | | $\frac{7}{12}$ | 14 | 0.94 |
| 5 | 9 | $\frac{3}{12}$ | 11 | 0.95 | 9 | 6 | $\frac{3}{12}$ | 10 | 1.01 |
| | | $\frac{8}{12}$ | 11 | 0.90 | | | | | |
| | | $\frac{10}{12}$ | 10 | 0.94 | Total | 73 | ..... | 236 | |

For the coefficient for vertical curves for intermediate stations it is necessary to interpolate. In span No. 6 the vertical curves were taken closer together, for the reason that there is a sunken caisson in the bed of the river about 75 feet below the discharge section. The caisson is located directly below station $\frac{4}{12}$, and its effect is readily traceable in the cross section and curve of average velocity.

A mean transverse curve is formed from the individual transverse curves of each span by averaging the velocities at the $\frac{3}{10}$ depth

Fig. 1.

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point, these velocities in some cases being corrected for direction when near the piers. This mean transverse curve is reduced to a curve called the average-velocity curve by multiplying the average velocity at the $\frac{3}{10}$ depth point at each station by the respective coefficient for the vertical curves at that station. This curve is shown in plate 88 and gives the average velocity in any vertical plane and at any point of the cross section. The stage of the river corresponding to this curve in each span is taken as the mean of the observed stages during the times of the individual transverse curves.

*Mean-velocity coefficients.*—The observations for discharge, as already stated, were made at the $\frac{3}{10}$ depth point at meter stations, one in each one-half or one-third part of span. Assume for the present that the mean velocity in the one-half or one-third part of span will vary directly with the observed velocity at the $\frac{3}{10}$ depth point at the meter station.

The problem then is to find the ratio of these two quantities so as to change from observed velocity to mean velocity.

In connection with the transverse curves it will be remembered that observations were taken at the $\frac{3}{10}$ depth point at the meter stations. Compute the discharge for each one-half and one-third part of span, corresponding to the mean stage of the transverse curves. To do this, draw a discharge curve (plate 89), the points of the curve being obtained by multiplying the average velocity at any point by the corresponding depth at that point. The discharge equals the area of the figure and is easily found by means of the planimeter. Obtain the area of cross section for each one-half or one-third part of span, corresponding to the mean stage of the transverse curves. Discharge divided by area gives the mean velocity.

Then—

$$\text{Mean velocity Coefficient} = \frac{\text{Mean velocity } \frac{1}{2} \text{ or } \frac{1}{3} \text{ span.}}{\text{Mean of observed velocities at } \frac{3}{10} \text{ depth point at meter station.}}$$

It has been assumed that this coefficient would be constant. To investigate the subject, consider the discharge from each one-half or one-third part of span as forming a solid, the cross section being the base and the velocities the ordinates. The coefficient and form of the vertical curve at the meter station are known from observation. The coefficient for the vertical curves in the width of one-half or one-third part of span will not vary more than 2 or 3 per cent, and may be taken as constant for this discussion. Velocities located by percentages of the depth will all vary in the same proportion. The mean-velocity coefficient would be constant under the following conditions:

1. The cross section remaining constant while all the ordinates of the solid increase or decrease in the same proportion.

2. The cross section to remain of the same form while ordinates of the solid, located at similar points of the cross section, remain constant, increase or decrease in the same proportion.

3. The velocities located by percentages of the depth to remain constant, while the volume and area of cross section increase or decrease in the same proportion.

A change of form under condition 1 is possible, and as all ordinates change in the same proportion it is evident that the mean-velocity coefficient will remain constant.

A change of the cross section to one of a similar form can not take place when the sides of the cross section are vertical. In general, then, we must expect a slight change in the mean-velocity coefficient when the stage varies.

Condition 3, followed or preceded by a change under condition 1, covers all cases where the mean-velocity coefficient can remain constant. The simplest case in which these two conditions are satisfied is that of a rectangular cross section. To find the effect of a change of stage on the mean-velocity coefficient, for the particular solids we have, a range of stage of 5 feet has been considered, $2\frac{1}{2}$ feet above and $2\frac{1}{2}$ feet below the mean stage of each span, corresponding to the transverse curves. Assume the velocities at precentages of the depth to remain constant. Any requisite change in depth can be made in this way with some resulting change in the area of the cross section and volume of the solid. Then with the area of cross section remaining constant all ordinates can be increased or decreased proportionally and will not affect the mean-velocity coefficient. So the only change that it is required to investigate is the change of area of cross section and volume, while the velocities at percentages of depth remain constant. If these two quantities increase or decrease in the same proportion, the mean velocity-coefficient will remain constant.

For a rise of river stage the area of cross section will be increased by the product of the width and increase in depth of water. The volume of the solid has already been computed for each one-half or one-third span from the curve of average velocities. This will be increased by an amount represented in one of the vertical curves (fig. 1) by A and decreased by the amount represented by B.

The volume represented by A is obtained as follows: Find the area of one-half or one-third span of the curve of average velocities and divide this by the

$$\text{ratio} = \frac{\text{Average velocity in vertical plane}}{\text{Surface velocity}}$$

obtained from the mean vertical curve at the meter station. This will give the area of the base of the solid A; the height will be the increase in the depth of water. The volume of the solid represented by B is obtained as follows: The form of the vertical curve at any point can be determined from the vertical at the meter station. It can be easily proven that the areas represented by B are proportional to the horizontal projections of the vertical curves at the respective points; but the horizontal projections are in the same ratios as the

average velocities. So we have the area represented by B at any point is proportional to the average velocity at that point. The volume can then be easily computed.

In general for the solids we have both area of cross section and volume increase in about the same proportion. The following table gives the results of the computations for the mean-velocity coefficients:

TABLE NO. 4.—*Mean velocity coefficients for computing discharge measurements.*

| Span No. | | Elevation of water surface at discharge section above mean tide at New York. | | | | | |
|---|---|---|---|---|---|---|---|
| | | 564. | 565. | 566. | 567. | 568. | 569. |
| 1 | East ⅓ | 0.80 | 0.82 | 0.85 | 0.89 | 0.90 | 0.92 |
| | West ⅓ | .63 | .65 | .62 | .62 | .61 | .61 |
| 2 | East ⅓ | .93 | .93 | .93 | .92 | .92 | .91 |
| | West ⅓ | .95 | .95 | .95 | .95 | .95 | .95 |
| 3 | East ⅓ | .91 | .90 | .89 | .88 | .86 | .85 |
| | West ⅓ | .82 | .82 | .82 | .82 | .81 | .81 |
| 4 | East ⅓ | .91 | .91 | .91 | .91 | .91 | .91 |
| | Middle ⅓ | .91 | .91 | .91 | .91 | .91 | .91 |
| | West ⅓ | .86 | .86 | .86 | .86 | .85 | .85 |
| 5 | East ⅓ | .94 | .94 | .94 | .94 | .94 | .94 |
| | Middle ⅓ | .91 | .91 | .92 | .92 | .92 | .92 |
| | West ⅓ | .91 | .91 | .90 | .90 | .90 | .90 |
| 6 | East ⅓ | .86 | .86 | .87 | .87 | .87 | .87 |
| | Middle ⅓ | .88 | .88 | .89 | .89 | .89 | .89 |
| | West ⅓ | .81 | .81 | .80 | .80 | .80 | .80 |
| 7 | East ⅓ | .80 | .80 | .79 | .79 | .79 | .78 |
| | West ⅓ | .91 | .91 | .91 | .91 | .90 | .90 |
| 8 | East ⅓ | .93 | .93 | .93 | .93 | .92 | .92 |
| | West ⅓ | .93 | .93 | .93 | .93 | .93 | .93 |
| 9 | East ⅓ | 1.15 | 1.15 | 1.14 | 1.12 | 1.12 | 1.11 |
| | West ⅓ | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 |

The observations of the individual vertical and transverse curves being approximately at the mean stage of the river, 566.5, the mean velocity coefficients for this stage are practically independent of any assumption in regard to the change in the form of the vertical curves when the stage varies.

The mean velocity coefficient does not follow any regular law as the stage changes, but depends simply, as stated, on the relative increase or decrease of the quantities and of cross section and volume of solid when the velocities at percentages of the depth are assumed to remain constant.

The effect of a triangular cross section in general is to make the mean velocity coefficient decrease as the stage increases, but the form of the solid may be such as to more than balance this effect and even reverse the law.

It will be seen that the variation of the mean velocity coefficient for a change from low stage to high stage does not exceed about 2 per cent, and generally decreases.

*Curves of fall on Niagara River* (*plate 89*).—This plate shows graphically the fall, in feet, from Lake Erie to the various gauges which are read. The curves were obtained from simultaneous gauge readings taken at ten-minute intervals throughout the day. From these gauge readings daily means and means of one-third part of the day were worked out and used as individual observations for determining the

fall. Thus the daily mean is the mean of 60 readings, and the mean for one-third part of the day the mean of 20 readings.

The falls computed from these means were then platted and a straight line or curve fitted to the points. Considerable care has been taken in the selection of observations to see that the lake gauge 1 L or 2 L was not fluctuating too much and that the slope conditions remained fairly stationary. The following table gives the data in connection with the curves:

TABLE No. 5—*Curves of fall of Niagara River.*

| Gauge No. | Distance from gauge No. 2. | Equations of curves: $x$ being fall from lake level in feet. $y$ being elevation of lake above 570. | Variation in $y$ covered by observations obtained. | Number of observations (see Index). |
|---|---|---|---|---|
| | *Feet.* | | | |
| 1 | (1) | $x=0.13$ | 1.8 to 2.6 | 36 |
| 2 C | 0 | $x=0.678+0.010\,(y)$ | 1.8 to 2.7 | 56 |
| 2 | 0 | $x=1.0944-0.4714\sqrt{3.14014-y}$ for $y \leqq 2.70$<br>$x=-0.1776+0.3553\,(y)$ for $y \geqq 2.70$ | 1.8 to 2.7 | 67 |
| 2 D | 1,220 | $x=1.326+0.037\,(y)$ | 2.0 to 2.7 | ..... |
| 2 A | 2,550 | $x=1.606+0.037\,(y)$ | 1.8 to 2.7 | 56 |
| 2 B | 3,260 | $x=1.976+0.037\,(y)$ | 1.8 to 2.7 | 56 |
| 2 E | 3,780 | $x=2.636+0.081\,(y)$ | 2.0 to 2.7 | 12 |
| 3 | 4,370 | $x=2.981+0.081\,(y)$ | 1.25 to 2.7 | 92 |
| 3 A | 5,550 | $x=4.5846-0.4714\sqrt{3.09389-y}$ for $y \leqq 2.45$<br>$x=3.486+0.294\,(y)$ for $y \geqq 2.45$ | 1.8 to 2.7 | 16 |
| 4 | 7,070 | $x=4.8126-0.4714\sqrt{3.09389-y}$ for $y \leqq 2.45$<br>$x=3.714+0.294\,(y)$ for $y \geqq 2.45$ | 1.8 to 2.8 | 67 |
| 6 | 12,250 | $x=5.2444-0.4714\sqrt{3.09389-y}$ for $y \leqq 2.70$<br>$x=3.9334+0.376\,(y)$ for $y \geqq 2.70$ | 1.25 to 2.8 | 92 |
| 7 | 12,250 | $x=5.3244-0.4714\sqrt{3.09389-y}$ for $y \leqq 2.70$<br>$x=4.0134+0.376\,(y)$ for $y \geqq 2.70$ | 1.8 to 2.8 | ..... |
| 8 | 15,250 | $x=5.5304-0.4714\sqrt{3.09389-y}$ for $y \leqq 2.70$<br>$x=4.2194+0.376\,(y)$ for $y \geqq 2.70$ | 1.8 to 2.8 | ..... |

[1] Erie Basin.

The distances from gauge No. 2 have been measured along the center line of the river in about the mean direction of flow.

The range in fall of the individual observations in gauges Nos. 1, 2, and 2 C was about 0.04 foot; in gauges 2 B, 2 A, and 2 C, about 0.10 foot, and in the remaining gauges about 0.15 foot.

Within the limit of the observations the curves are thought to be quite reliable; beyond these limits they should be taken simply as an approximation.

*Computations for discharge.*—The mean velocity for each one-half or one-third span is obtained by multiplying the observed velocity at $\frac{3}{10}$ depth by the mean velocity coefficient. This mean velocity multiplied by the area of cross section of the one-half or one-third span for the observed stage gives discharge of this part of the span. The sum of the partial discharge gives total discharge. The following tables give the reductions of one of the measurements:

TABLE NO. 6.—*Discharge measurement No. 13.*

[Direction meter A, No. 12. December 3, 1897.]

| | Station. | Time of day. | Elevation of water surface at section. | Velocity observed at $\frac{2}{10}$ depth. | Mean velocity coefficient. | Mean velocity. | Area of cross section. | Discharge per second. | Discharge by spans. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | *Cu. feet.* | |
| 1 | $\frac{3}{8}$ | 8.12 | 565.85 | 1.63 | 0.85 | 1.39 | 408 | 567 | 1,585 |
| | $\frac{5}{8}$ | 8.18 | 565.86 | 2.44 | .62 | 1.51 | 674 | 1,018 | |
| 2 | $\frac{7}{8}$ | 8.30 | 565.88 | 2.59 | .93 | 2.41 | 720 | 1,735 | 3,830 |
| | $\frac{9}{8}$ | 8.50 | 565.89 | 2.71 | .95 | 2.57 | 815 | 2,095 | |
| 3 | $\frac{11}{8}$ | 8.55 | 565.78 | 4.75 | .89 | 4.23 | 1,963 | 8,304 | 16,967 |
| | $\frac{13}{8}$ | 9.00 | 565.77 | 5.22 | .82 | 4.28 | 2,024 | 8,663 | |
| 4 | $\frac{15}{8}$ | 9.14 | 565.77 | 5.51 | .91 | 5.01 | 2,623 | 13,136 | 52,056 |
| | $\frac{17}{8}$ | 9.18 | 565.77 | 6.08 | .91 | 5.53 | 3,890 | 21,512 | |
| | $\frac{19}{8}$ | 9.20 | 565.77 | 6.52 | .86 | 5.61 | 3,103 | 17,408 | |
| | $\frac{21}{8}$ | 9.26 | 565.78 | 6.19 | .94 | 5.82 | 3,101 | 18,048 | |
| 5 | $\frac{23}{8}$ | 9.31 | 565.79 | 5.88 | .92 | 5.41 | 3,005 | 16,257 | 48,884 |
| | $\frac{25}{8}$ | 9.40 | 565.78 | 6.12 | .90 | 5.51 | 2,646 | 14,579 | |
| | $\frac{27}{8}$ | 9.46 | 565.77 | 5.84 | .87 | 5.08 | 2,426 | 12,324 | |
| 6 | $\frac{29}{8}$ | 9.53 | 565.76 | 5.30 | .89 | 4.72 | 2,638 | 12,451 | 31,214 |
| | $\frac{31}{8}$ | 9.57 | 565.77 | 5.51 | .80 | 4.41 | 1,460 | 6,439 | |
| 7 | $\frac{33}{8}$ | 10.02 | 565.78 | 4.96 | .79 | 3.92 | 1,710 | 6,703 | 13,649 |
| | $\frac{35}{8}$ | 10.06 | 565.79 | 4.46 | .91 | 4.06 | 1,711 | 6,946 | |
| 8 | $\frac{37}{8}$ | 10.10 | 565.80 | 4.35 | .93 | 4.05 | 1,252 | 5,071 | 9,061 |
| | $\frac{39}{8}$ | 10.14 | 565.80 | 3.82 | .93 | 3.55 | 1,124 | 3,990 | |
| 9 | $\frac{41}{8}$ | 10.18 | 565.80 | 2.43 | 1.14 | 2.77 | 295 | 817 | 875 |
| | $\frac{43}{8}$ | ------ | ------ | [1]1.43 | 1.17 | 1.67 | 55 | 58 | |

[1] Approximate.

Total, 178,121.

TABLE No. 7.—*Discharge measurements of Niagara River.*

| No. of observation. | Date of observation. | Weighted elevation of water surface of gauge numbers above mean tide at New York. | | | | | | Elevation of lake at Buffalo above mean tide at New York. | | | | Elevation of lake at Cleveland above mean tide at New York. | Relation of elevation of lake at Buffalo to elevation of lake at Cleveland, above +, below −. | Water surface at lake during observation. Rising +. Falling −. | | | | | Discharge per second. | Direction and velocity of wind (miles per hour). | Observations accepted — marked — |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 L or 2 L. | 1 | 2 and 2c. | 3. | 4. | 6. | Computed from gauge No. 1. | Computed from gauge No. 2. | Computed from gauge No. 3. | Elevation used. | | | Span No. | To— | Span No. | To— | Span No. | | | |
| *a* | *b* | *c* | *d* | *e* | *f* | *g* | *h* | *i* | *j* | *k* | *l* | *m* | *n* | | *o* | | *p* | | *q* | *r* | *s* |
| | 1897. | | *Feet.* | 2 | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | | *Feet.* | | *Feet.* | | *Cu. ft. sec.* | | |
| 1 | Nov. 2 | ..... | 569.83 | 569.61 | 566.40 | 565.46 | 565.05 | 569.96 | 569.85 | 569.30 | 569.85 | 571.42 | − 1.57 | 1 | +0.8 | 9 | ..... | ..... | 158,780 | NE. 15 | |
| 2 | Nov. 3 | ..... | 71.44 | 71.04 | 8.39 | 7.32 | 6.88 | 71.57 | 71.54 | 71.49 | 71.54 | 1.41 | +0.13 | 1 | −0.3 | 9 | ..... | ..... | 196,960 | W. 15 | |
| 3 | Nov. 6 | ..... | 72.87 | 71.98 | 9.75 | 8.60 | 8.13 | 73.00 | 72.80 | 72.98 | 72.80 | 1.40 | +1.40 | 1 | −0.2 | 4 | +0.6 | 9 | 219,080 | W. 40 | |
| 4 | ...do... | ..... | 73.02 | 72.11 | 9.86 | 8.70 | 8.21 | 73.15 | 72.99 | 73.11 | 72.99 | 1.40 | +1.59 | 9 | −0.9 | 4 | +0.4 | 1 | 226,870 | W. 40 | |
| 5 | Nov. 9 | ..... | 69.97 | 69.72 | 6 85 | 5.85 | 5.49 | 70.10 | 69.98 | 69.80 | 69.98 | 1.38 | −1.40 | 1 | −1.2 | 4 | +1.6 | 9 | 156,930 | N. 20 | |
| 6 | ...do... | ..... | 72.46 | 71.70 | 8.72 | 7.28 | 6.69 | 72.59 | 72.38 | 71.85 | 72.38 | 1.38 | +1.00 | 9 | +1.6 | 3 | −0.4 | 1 | 216,830 | NW. 20 | |
| 7 | ...do... | ..... | 72.04 | 71.45 | 8.99 | 7.85 | 7.42 | 72.17 | 72.05 | 72.15 | 72.05 | 1.38 | +0.67 | 1 | −0.9 | 9 | ..... | ..... | 208,200 | NW. 25 | |
| 8 | Nov. 11 | ..... | 73.70 | ..... | 70.24 | 8.76 | 8.03 | 73.83 | ..... | 73.53 | 73.53 | 1.38 | +2.15 | 1 | +0.7 | 3 | −0.8 | 9 | 253,080 | SW. 20 | |
| 9 | Nov. 12 | ..... | 73.44 | ..... | 70.11 | 8 82 | 8 25 | 73.57 | ..... | 73.38 | 73.38 | 1.37 | +2.01 | 1 | +0.6 | 4 | 0.4 | 9 | 242,580 | W. 40 | |
| 10 | ...do... | ..... | 72.74 | ..... | 69.68 | 8.55 | 8.06 | 72.87 | ..... | 72.91 | 72.91 | 1.37 | +1.54 | 1 | −0.2 | 9 | ..... | ..... | 217,900 | W. 40 | |
| 11 | ...do... | ..... | 73.06 | ..... | 9.84 | 8.63 | 8 10 | 73.19 | ..... | 73.09 | 73.09 | 1.37 | +1.72 | 9 | +0.3 | 5 | −0.2 | 1 | 229,800 | W. 40 | |
| 12 | Nov. 29 | ..... | 72.34 | 71.67 | 9 11 | 7.84 | 7.35 | 72.47 | 72.35 | 72.28 | 72.35 | 1.35 | +1.00 | 1 | −0.3 | 5 | +0.9 | 9 | 219,710 | W. 30 | |
| 13 | Dec. 3 | ..... | 70.41 | 70.18 | 7.32 | 6.26 | 5 88 | 70.54 | 70.51 | 70.31 | 70.51 | 1.34 | −0.83 | 1 | +0.2 | 9 | ..... | ..... | 178,120 | E. 12 | |
| 14 | ...do... | ..... | 70.51 | 70.27 | 7.41 | 6.30 | 5.91 | 70 64 | 70.61 | 70.41 | 70.61 | 1.34 | −0.73 | 9 | +0.2 | 4 | −0.1 | 1 | 177,700 | NE. 15 | |
| 15 | Dec. 15 | ..... | 71.84 | 71.39 | 8.73 | 7.44 | 6.97 | 71.97 | 71.97 | 71.86 | 71.97 | 1.33 | +0.64 | 1 | +0 4 | 9 | ..... | ..... | 208,840 | W. 10 | |
| 16 | ...do... | ..... | 71.86 | 71.32 | 8.70 | 7.55 | 7.06 | 71.99 | 71.89 | 71.83 | 71.89 | 1.33 | +0.56 | 9 | −0.3 | 1 | ..... | ..... | 208,530 | W. 15 | |
| | 1898. | | | 2c | | | | | | | | | | | | | | | | | |
| 17 | July 16 | 572.15 | ..... | 571.47 | 8.98 | 7.77 | 7.31 | ..... | ..... | ..... | 72.15 | 2.37 | −0.22 | 1 | +0.1 | 3 | 0.0 | 9 | 216,330 | NE. 10 | |
| 18 | ...do... | 72.17 | ..... | 1.48 | 8.97 | 7.76 | 7.31 | ..... | ..... | ..... | 72.17 | 2.37 | −0.20 | 1 | +0.2 | 9 | ..... | ..... | 217,400 | N. 10 | |
| 19 | July 18 | 72.48 | ..... | 1.78 | 9.23 | 7.93 | 7.47 | ..... | ..... | ..... | 72.48 | 2.36 | +0.12 | 1 | +0.4 | 9 | ..... | ..... | 225,620 | SW. 15 | |
| 20 | July 19 | 72.20 | ..... | 1.49 | 9 03 | 7.85 | 7.42 | ..... | ..... | ..... | 72.20 | 2.35 | 0.15 | 1 | −0.1 | 4 | +0.2 | 9 | 212,560 | SW. 15 | |
| 21 | July 20 | 72.20 | ..... | 1.52 | 9.01 | 7.82 | 7.38 | ..... | ..... | ..... | 72.20 | 2.35 | 0.15 | 1 | +0.1 | 3 | 0.0 | 9 | 217,450 | W. 10 | |
| 22 | July 21 | 72.63 | ..... | 1.93 | 9.45 | 8.20 | 7.76 | ..... | ..... | ..... | 72.63 | 2.34 | +0.29 | 1 | −0.2 | 4 | +0.1 | 9 | 225,670 | NW. 10 | |
| 23 | July 22 | 72.08 | ..... | 1.39 | 8.93 | 7.76 | 7.31 | ..... | ..... | ..... | 72.08 | 2.34 | −0.26 | 1 | +0.1 | 5 | −0.1 | 9 | 214,920 | E. 10 | |
| 24 | July 23 | 72.24 | ..... | 1.58 | 9.09 | 7.90 | 7.48 | ..... | ..... | ..... | 72.24 | 2 33 | −0.09 | 1 | −0.3 | 9 | ..... | ..... | 220,160 | W. 12 | |
| 25 | ...do... | 72.15 | ..... | 1.47 | 9.01 | 7.83 | 7.40 | ..... | ..... | ..... | 72.15 | 2.33 | −0.18 | 9 | +0 1 | 1 | ..... | ..... | 213,510 | NW. 10 | |
| 26 | July 25 | 72 34 | ..... | 1.65 | 9.20 | 7.95 | 7.55 | ..... | ..... | ..... | 72.34 | 2.32 | +0.02 | 1 | −0.2 | 5 | +0.3 | 9 | 218,750 | SW. 12 | |
| 27 | July 27 | 72.38 | ..... | 1.69 | 9.21 | 7.99 | 7.54 | ..... | ..... | ..... | 72.38 | 2.30 | +0.08 | 1 | 0.2 | 9 | ..... | ..... | 213,120 | SW. 10 | |
| 28 | July 28 | 72.42 | ..... | 1.71 | 9.26 | 8 02 | 7.57 | ..... | ..... | ..... | 72.42 | 2 30 | +0.12 | 1 | −0.2 | 9 | ..... | ..... | 211,620 | SW. 12 | |
| 29 | ...do... | 71.97 | ..... | 1.30 | 8.98 | 7.85 | 7.46 | ..... | ..... | ..... | 71.97 | 2.30 | −0.33 | 1 | −0.7 | 5 | +0.2 | 9 | 208,190 | W. 10 | |
| 30 | July 29 | 72.46 | ..... | 1.74 | 9.32 | 8.16 | 7.71 | ..... | ..... | ..... | 72.46 | 2.29 | +0.17 | 1 | −0.6 | 7 | +0.1 | 9 | 219,510 | SW. 14 | |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 31 | ....do.. | 72.54 | ..... | 1 85 | 9.39 | 8.12 | 7.70 | ..... | ..... | ..... | 72.54 | 2.29 | +0.25 | 9 | +0.3 | 1 | ..... | .. | 217,620 | SW. | 15 | | |
| 32 | ....do.. | 72.87 | ..... | 2 18 | 9.65 | 8.30 | 7.87 | ..... | ..... | ..... | 72.87 | 2.29 | +0.58 | 1 | +0.4 | 9 | ..... | .. | 225,480 | W. | 20 | | |
| 33 | ....do.. | 72.68 | ..... | 1.98 | 9.54 | 8.27 | 7.85 | ..... | ..... | ..... | 72.68 | 2.29 | +0.39 | 9 | −0.4 | 1 | ..... | .. | 224,240 | W. | 15 | | |
| 34 | Sept. 10 | 71.25 | ..... | ..... | 8.21 | ..... | 6.72 | ..... | ..... | ..... | 71.25 | 1.86 | −0.61 | 1 | −0.2 | 9 | ..... | .. | 188,600 | NE. | 8 | | |
| 35 | Sept. 13 | 71.84 | ..... | ..... | 8.74 | ..... | 7.12 | ..... | ..... | ..... | 71.84 | 1.83 | +0.01 | 1 | −0.2 | 9 | ..... | .. | 204,800 | SW. | 5 | | |
| 36 | ....do.. | 71.76 | ..... | ..... | 8.67 | ..... | 7.09 | ..... | ..... | ..... | 71.76 | 1.83 | −0.07 | 9 | −0.2 | 1 | ..... | .. | 203,900 | SW. | 5 | | |
| 37 | Sept. 15 | 71.96 | ..... | ..... | 8.84 | ..... | 7.18 | ..... | ..... | ..... | 71.96 | 1.80 | +0.16 | 9 | +0.4 | 1 | ..... | .. | 207,980 | SW. | 10 | | |
| 38 | ....do.. | 71.81 | ..... | ..... | 8.73 | ..... | 7.15 | ..... | ..... | ..... | 71.81 | 1.80 | +0.01 | 1 | −0.1 | 6 | +0.1 | 9 | 204,520 | SW. | 10 | | |
| 39 | Sept. 17 | 71.55 | ..... | ..... | 8.46 | ..... | 6.92 | ..... | ..... | ..... | 71.55 | 1.79 | −0.24 | 9 | −0.1 | 3 | +0.2 | 1 | 198,930 | SW. | 8 | | |
| 40 | Sept. 22 | 71.57 | ..... | ..... | 8.48 | ..... | 6.89 | ..... | ..... | ..... | 71.57 | 1.75 | −0.18 | 9 | +0.2 | 1 | ..... | .. | 199,730 | SW. | 10 | | |
| 41 | Oct. 1 | 71.23 | ..... | ..... | 8.14 | ..... | 6.63 | ..... | ..... | ..... | 71.23 | 1.70 | −0.47 | 1 | +0.1 | 9 | ..... | .. | 190,740 | SE. | 5 | | |
| 42 | do | 71.28 | ..... | ..... | 8.18 | ..... | 6.65 | ..... | ..... | ..... | 71.28 | 1.70 | −0.42 | 9 | +0.2 | 1 | ..... | .. | 193,150 | SE. | 3 | | |
| 43 | Oct. 6 | ..... | ..... | ..... | 8.14 | ..... | 6.64 | ..... | ..... | 71.21 | 71.21 | 1.66 | −0.45 | 1 | −0.1 | 5 | +0.1 | 9 | 190,440 | NE. | 5 | | |
| 44 | Oct. 17 | 70.94 | ..... | ..... | 7.93 | ..... | 6.43 | ..... | ..... | ..... | 70.94 | 1.59 | −0.65 | 1 | 0.0 | 9 | ..... | .. | 191,670 | SE. | 8 | | |
| 45 | ....do.. | 70.82 | ..... | ..... | 7.79 | ..... | 6.34 | ..... | ..... | ..... | 70.82 | 1.59 | −0.77 | 1 | −0.2 | 9 | ..... | .. | 183,520 | E. | 8 | | |
| 46 | ....do.. | 70.54 | ..... | ..... | 7.55 | ..... | 6.12 | ..... | ..... | ..... | 70.54 | 1.59 | −1.05 | 1 | −0.1 | 9 | ..... | .. | 181,620 | SE. | 10 | | |
| 47 | ....do.. | 70.44 | ..... | ..... | 7.45 | ..... | 6.05 | ..... | ..... | ..... | 70.44 | 1.59 | −1.15 | 9 | −0.2 | 1 | ..... | .. | 176,800 | SE. | 10 | | |
| 48 | Oct. 19 | 71.22 | ..... | ..... | 8.20 | ..... | 6.72 | ..... | ..... | ..... | 71.22 | 1.58 | 0.36 | 1 | +0.4 | 9 | ..... | .. | 188,170 | SW. | 10 | | |
| 49 | Oct. 22 | ..... | ..... | ..... | 70.16 | ..... | 8.63 | ..... | ..... | 73.44 | 73.44 | 1.57 | +1.87 | 1 | 0.6 | 9 | ..... | .. | 233,920 | SW. | 30 | | |
| 50 | Oct. 25 | 71.46 | ..... | ..... | 68.34 | ..... | 6.84 | ..... | ..... | ..... | 71.46 | 1.56 | −0.10 | 1 | −0.1 | 5 | +0.0 | 9 | 197,640 | SW. | 10 | | |
| 51 | Nov. 2 | 71.66 | ..... | ..... | 8.62 | ..... | 7.12 | ..... | ..... | ..... | 71.66 | 1.53 | +0.13 | 1 | +0.1 | 9 | ..... | .. | 203,760 | W. | 10 | | |
| 52 | ....do.. | 71.63 | ..... | ..... | 8.54 | ..... | 7.04 | ..... | ..... | ..... | 71.63 | 1.53 | +0.10 | 9 | 0.2 | 1 | ..... | .. | 201,860 | W. | 12 | | |
| 53 | Nov. 4 | 71.40 | ..... | ..... | 8.22 | ..... | 6.68 | ..... | ..... | ..... | 71.40 | 1.52 | −0.12 | 1 | 0.1 | 6 | +0.1 | 9 | 196,520 | S. | 10 | | |
| 54 | ....do.. | 71.27 | ..... | ..... | 8.09 | ..... | 6.54 | ..... | ..... | ..... | 71.27 | 1.52 | −0.25 | 1 | +0.1 | 6 | −0.1 | 9 | 195,940 | S. | 7 | | |
| 55 | ....do.. | 71.24 | ..... | ..... | 8.08 | ..... | 6.54 | ..... | ..... | ..... | 71.24 | 1.52 | −0.28 | 9 | +0.0 | 1 | ..... | .. | 194,160 | S. | 7 | | |
| 56 | Nov. 9 | 69.89 | ..... | ..... | 6.95 | ..... | 5.72 | ..... | ..... | ..... | 69.89 | 1.50 | −1.61 | 1 | 0.4 | 9 | ..... | .. | 162,280 | NE. | 8 | | |
| 57 | ....do.. | 69.94 | ..... | ..... | 6.90 | ..... | 5.47 | ..... | ..... | ..... | 69.94 | 1.50 | −1.56 | 9 | +0.4 | 4 | −0.2 | 1 | 164,260 | NE. | 10 | | |
| 58 | ....do.. | ..... | ..... | ..... | 7.10 | ..... | 5.57 | ..... | ..... | 70.07 | 70.07 | 1.50 | −1.43 | 1 | +0.1 | 9 | ..... | .. | 169,790 | NE. | 12 | | |
| 59 | Nov. 10 | 69.79 | ..... | ..... | 6.71 | ..... | 5.34 | ..... | ..... | ..... | 69.79 | 1.50 | −1.71 | 1 | +0.1 | 9 | ..... | .. | 160,960 | NE. | 10 | | |
| 60 | ....do.. | ..... | ..... | ..... | 6.72 | ..... | 5.36 | ..... | ..... | 69.65 | 69.65 | 1.50 | −1.85 | 9 | +0.1 | 6 | −0.2 | 1 | 161,460 | NE. | 12 | | |
| 61 | ....do.. | 70.04 | ..... | ..... | 6.87 | ..... | 5.41 | ..... | ..... | ..... | 70.04 | 1.50 | −1.46 | 1 | +0.6 | 9 | ..... | .. | 168,720 | NE. | 10 | | |
| 62 | Nov. 15 | ..... | ..... | ..... | 9.68 | ..... | 7.76 | ..... | ..... | 72.91 | 72.91 | 1.48 | +1.43 | 1 | +0.2 | 5 | −0.1 | 9 | 238,080 | SW. | 20 | | |
| 63 | Nov. 16 | 71.24 | ..... | ..... | 8.03 | ..... | 6.45 | ..... | ..... | ..... | 71.24 | 1.48 | −0.24 | 9 | 0.1 | 5 | +0.1 | 1 | 191,700 | SE. | 8 | | |
| 64 | Nov. 22 | 71.60 | ..... | ..... | 8.23 | ..... | 6.61 | ..... | ..... | ..... | 71.60 | 1.44 | +0.16 | 1 | 0.1 | 9 | ..... | .. | 200,370 | SE. | 10 | | |
| 65 | Nov. 26 | 71.24 | ..... | ..... | 8.02 | ..... | 6.45 | ..... | ..... | ..... | 71.24 | 1.42 | −0.18 | 1 | +0.1 | 9 | ..... | .. | 191,310 | E. | 10 | | |
| 66 | Nov. 29 | 71.26 | ..... | ..... | 8.06 | ..... | 6.50 | ..... | ..... | ..... | 71.26 | 1.39 | −0.13 | 1 | −0.1 | 9 | ..... | .. | 197,170 | SE. | 3 | | |
| 67 | ....do.. | 71.35 | ..... | ..... | 8.14 | ..... | 6.53 | ..... | ..... | ..... | 71.35 | 1.39 | −0.04 | 9 | +0.2 | 5 | −0.1 | 1 | 195,220 | SE. | 5 | | |
| 68 | Dec. 7 | ..... | ..... | ..... | 70.06 | ..... | 8.19 | ..... | ..... | 73.33 | 73.33 | 1.35 | +1.98 | 1 | 0.2 | 9 | ..... | .. | 244,460 | W. | 15 | | |
| 69 | Dec. 8 | ..... | ..... | ..... | 69.51 | ..... | 7.78 | ..... | ..... | 72.72 | 72.72 | 1.35 | +1.37 | 1 | 0.1 | 9 | ..... | .. | 228,510 | W. | 20 | | |
| 70 | Dec. 10 | ..... | ..... | ..... | 70.36 | ..... | 8.50 | ..... | ..... | 73.66 | 73.66 | 1.34 | +2.32 | 1 | +0.1 | 9 | ..... | .. | 248,070 | W. | 25 | | |
| 71 | ....do.. | ..... | ..... | ..... | 70.37 | ..... | 8.49 | ..... | ..... | 73.67 | 73.67 | 1.34 | +2.33 | 1 | +0.1 | 5 | 0.1 | 9 | 251,100 | W. | 25 | | |
| 72 | ....do.. | 73.30 | ..... | ..... | 70.18 | ..... | 8.38 | ..... | ..... | ..... | 73.30 | 1.34 | +1.96 | 9 | −0.2 | 5 | +0.1 | 1 | 241,230 | W. | 25 | | |

[Measurements Nos. 34 to 72 were furnished by the United States Lake Survey.]

Table No. 7 gives a list of all the discharges. Columns *c*, *d*, *e*, *f*, *g*, and *h* give the weighted elevation of the water surface at the various gauges at the time of the discharge measurement. The elevations were determined from simultaneous gauge readings taken at ten-minute intervals. The gauge readings were worked out which correspond with the time of observing for discharge in each span. These readings were then weighted in the proportion of the discharge of the respective spans, thus giving a weighted mean elevation of water surface during the time of the discharge. Gauges 1 L and 2 L were taken as the lake gauge. They gave results for lake level which agreed within 0.01 foot, so either could be taken. In some instances it will be noted the lake gauge has not been read, and in such cases it was necessary to use some other gauge as a base from which to compute the lake level. Columns *i*, *j*, and *k* give these computed lake elevations. The working up of the gauge records showed that gauge No. 1 was not a reliable base from which to compute lake level. The gauge is located in Erie Basin, and the entrance is protected by breakwaters. With the lake surface fluctuating rapidly the water surface in Erie Basin would lag behind that of the lake surface. This, together with local currents around the breakwater resulting from winds and Buffalo Creek, seemed to justify the throwing out of readings on this gauge as furnishing a base for lake level.

Lake elevations computed from gauge No. 2 are given the preference where this gauge has been read. The law for the fall from lake to gauge No. 2 is well determined within the limits of the observations for fall, and even beyond these limits, with slope conditions fairly stationary, the error of a computed lake elevation would probably not exceed about 0.05 foot. The error from gauge No. 3 under the same conditions would probably not exceed about 0.10 foot. Column *m* gives the elevations of the lake at Cleveland for the dates of the discharge measurements. These elevations are a good approximation to the mean elevation of the lake for the respective dates, and have been taken as such. Column *n* gives the amount the water was raised or lowered from the mean level under the influence of wind. Columns *o* and *p* give the fluctuations of the level during the measurement.

In working up the results of these measurements, in place of considering all observations, and with equal or unequal weights, it was thought a more reliable law of the relation of discharge to lake level could be obtained by taking selected observations.

To this end the following arbitrary limits were used in the selection of discharge observations:

Elevations of Lake Erie at Buffalo: Not to exceed 0.60 foot above elevation of lake at Cleveland; not to exceed 1.20 feet below elevation of lake at Cleveland.

Fluctuation of lake level during observation: Not to exceed 0.50 foot.

Wind velocity: Not to exceed 15 miles per hour (fresh to brisk).

It will be noted from the table of discharges that with strong winds the slope conditions are very changeable and gauge fluctuating. With the wind from the northeast or southwest the water is raised or lowered, respectively, from the mean level of the lake, and there is danger of the discharge being influenced by the conflict of the return current and current in the river. It is thought that, with the limits used, only the most reliable discharges have been included. Out of the 72 discharges, 43 have been accepted, and cover a range in lake stage of about 2.3 feet. A curve has been adjusted to fit these 43 observations by the method of least squares, giving each observation a weight of unity. The equation of the curve is—

$$x = 168812 + 17762\,(y) + 1409\,(y)^2$$

where $x$ is the discharge in cubic feet per second and $y$ the elevation of Lake Erie in feet above 570.

This curve has been plotted on plate 89, together with the discharges taken from Table No. 7.

In the measurements, where the lake level has not been directly observed there may be a slight error in the values used, but the changing of these elevations by 0.05 or 0.10 foot will not affect the position of the discharge curve by more than one-fourth of 1 per cent. Measurement No. 28, while complying with the limits for the selection of observations, seems so far outside the range of the other measurements as to indicate some unusual condition in the slopes, and it has accordingly been rejected.

The greatest error of an accepted observation from the discharge curve is about 6,000 cubic feet per second, or about 2.7 per cent.

The range in the discharge measurements at any lake stage is about 5 per cent. It should be remarked that outside the limit of the observations the curve can only be expected to give an approximate discharge.

In closing this report, the writer wishes to acknowledge the valuable assistance of Mr. G. B. Mitchell, who has assisted in making the reductions.

Very respectfully, C. B. STEWART,
*Assistant Engineer.*

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

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## APPENDIX NO. 8.

### REGULATION OF LAKE CHAMPLAIN.

The proposed project for a ship canal from Lake Ontario to the Atlantic via the St. Lawrence and Hudson rivers requires that the supply of water for locks south of Lake Champlain and for power for the operation of gates, be taken from Lake Champlain at times of low

water, and in order to secure an adequate flow from Whitehall to Fort Edward the level of the lake must be maintained at about 100 feet elevation above tide water. Any less elevation than 100 feet for the summit level will add greatly to the cost of construction, and any rise above the natural high-water stage will cause damage to private property around the lake and make it necessary to construct regulating works to control the flow through the canal.

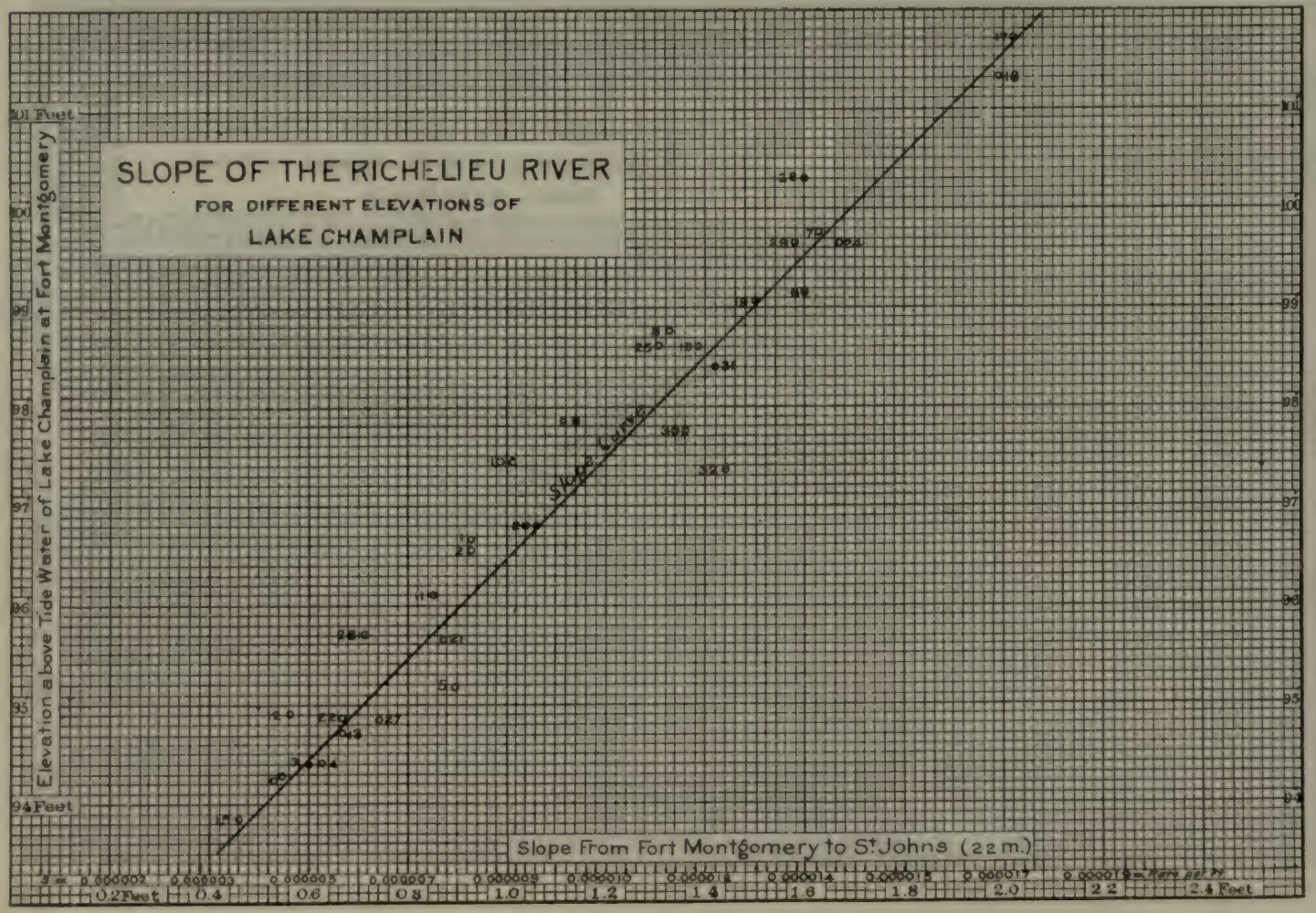
The greatest known range of the lake levels is about 10 feet and the greatest range of the monthly mean levels about 6.5 feet. The fall of the Richelieu River varies in a distance of 22 miles from 0.4 foot, when the lake is at elevation of 93.5, to 2 feet for lake at elevation of 101.5 above tide water.

The discharge of the Richelieu River for different elevations of Lake Champlain has been computed from the corresponding depths on the crest of the dam at Chambly, and is as follows (see figs. 1 and 2):

| Elevation of lake at Fort Montgomery. | Discharge of the Richelieu River at Chambly (cubic feet per second). | Elevation of lake at Fort Montgomery. | Discharge of the Richelieu River at Chambly (cubic feet per second). |
|---|---|---|---|
| 94 | 5,000 | 98 | 19,500 |
| 95 | 8,500 | 99 | 24,000 |
| 96 | 12,000 | 100 | 29,500 |
| 97 | 15,500 | 101 | 36,000 |

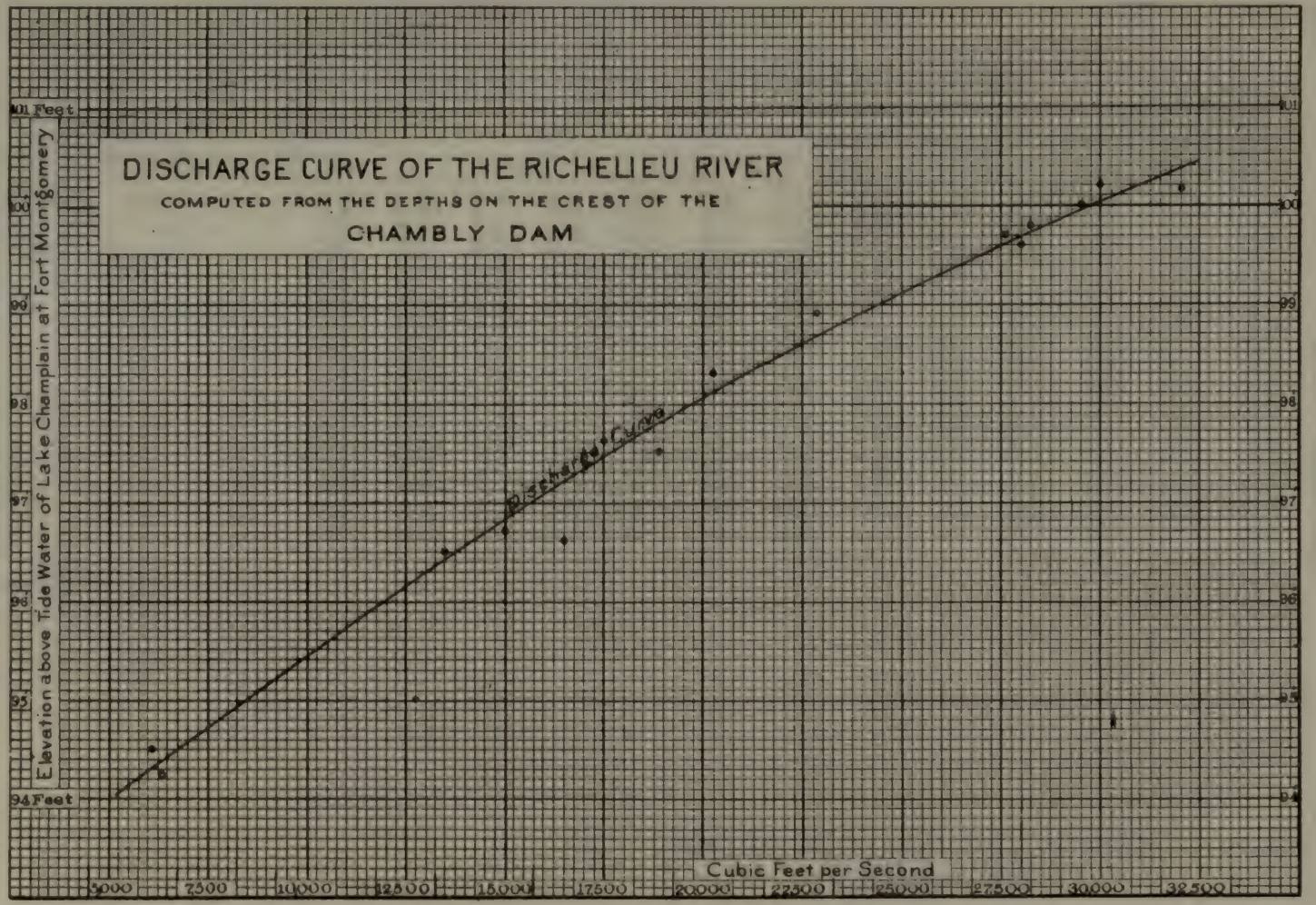
The net supply to the lake for any given period is equal to the sum of the discharge and storage for the same time.

The area of Lake Champlain is 436.7 square miles, and a rise of 1 foot per month is equivalent to storage at the rate of 4,632 cubic feet per second. The following tables give the monthly mean elevations of the lakes, the corresponding discharge of the Richelieu River, and the monthly mean supply to the lake when rising, from 1875 to 1898, inclusive:

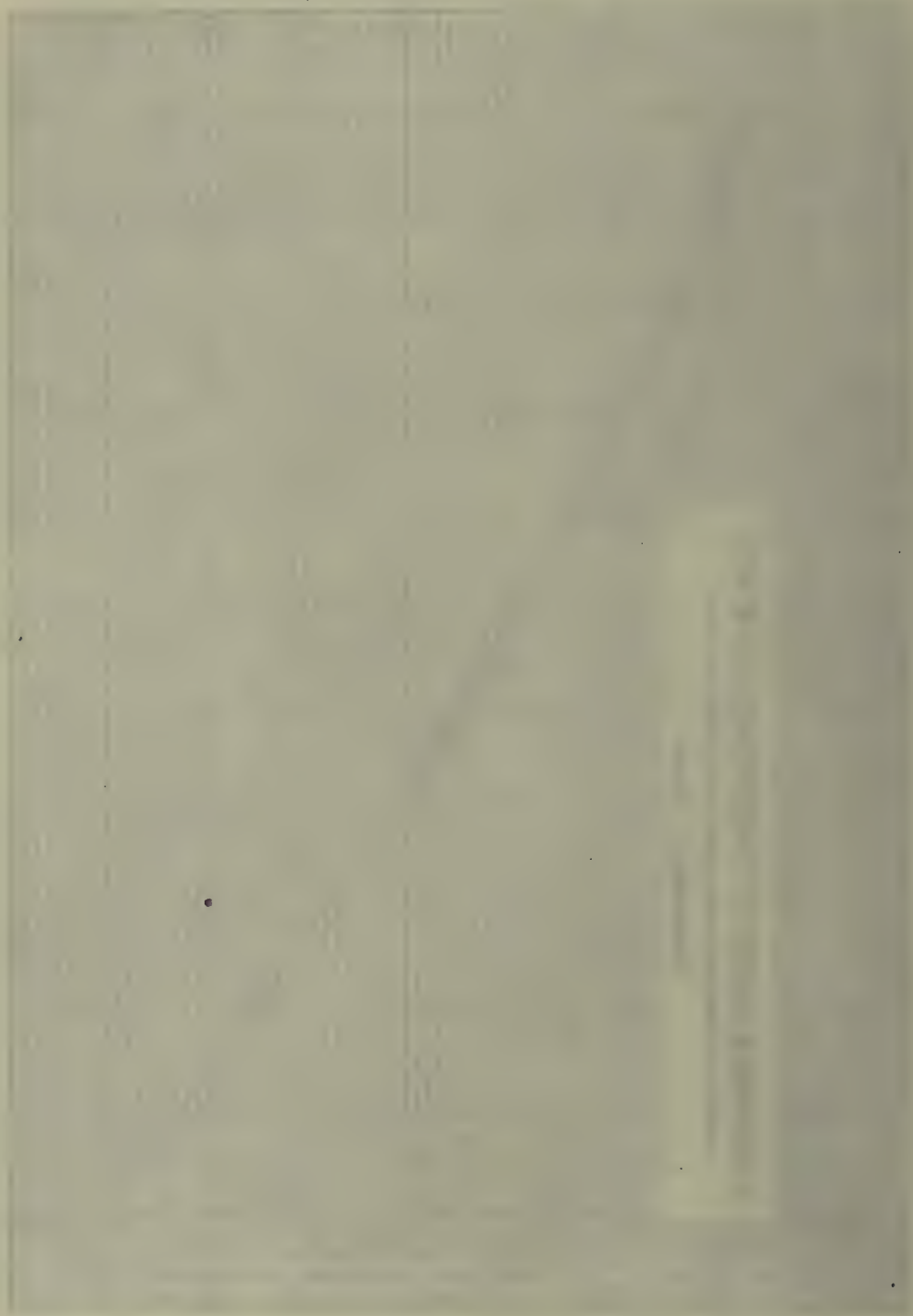

SLOPE OF THE RICHELIEU RIVER
FOR DIFFERENT ELEVATIONS OF
LAKE CHAMPLAIN
Elevation above Tide Water of Lake Champlain at Fort Montgomery
101 Feet
94 Feet
Slope From Fort Montgomery to St Johns (22 m.)
J = 0.000002 0.000003 0.000005 0.000007 0.000009 0.000010 0.000013 0.000014 0.000015 0.000017 0.000019 = Fore pel Ft.
0.2 Feet 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4 Feet

U.S.H.

JULIUS BIEN & CO PHOTO LITH




JULIUS BIEN & CO PHOTO LITH



*Monthly mean elevations of Lake Champlain at Fort Montgomery, N. Y., 1875 to 1898.*

| Year. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Means, 1 year. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| 1875 | 94.22 | 94.24 | 95.09 | 97.88 | 98.41 | 97.07 | 95.94 | 95.30 | 94.92 | 95.24 | 96.09 | 95.81 | 95.85 |
| 1876 | 96.68 | 96.56 | 97.11 | 98.66 | 100.11 | 98.23 | 96.56 | 95.28 | 94.47 | 94.27 | 94.18 | 93.98 | 96.34 |
| 1877 | 93.96 | 94.04 | 94.97 | 97.86 | 97.39 | 95.93 | 95.72 | 95.50 | 95.06 | 94.89 | 95.72 | 96.10 | 95.60 |
| 1878 | 95.56 | 95.06 | 96.64 | 97.92 | 98.34 | 96.52 | 95.49 | 96.32 | 96.21 | 95.05 | 95.25 | 97.55 | 96.28 |
| 1879 | 96.82 | 96.20 | 96.51 | 97.94 | 99.50 | 97.23 | 96.00 | 95.14 | 94.52 | 94.16 | 94.31 | 95.74 | 96.17 |
| 1880 | 95.83 | 96.56 | 97.06 | 97.38 | 97.04 | 95.83 | 95.01 | 94.37 | 93.81 | 93.65 | 95.20 | 94.97 | 95.56 |
| 1881 | 94.54 | 94.94 | 96.56 | 96.96 | 98.13 | 96.71 | 95.49 | 94.88 | 94.44 | 94.12 | 94.56 | 95.04 | 95.53 |
| 1882 | 96.05 | 95.87 | 97.30 | 97.00 | 96.76 | 97.39 | 96.51 | 95.36 | 94.75 | 94.63 | 94.13 | 93.80 | 95.80 |
| 1883 | 93.70 | 94.00 | 94.52 | 97.55 | 98.48 | 97.52 | 96.43 | 95.30 | 94.56 | 93.90 | 93.90 | 93.96 | 95.30 |
| 1884 | 94.08 | 95.08 | 96.80 | 99.18 | 98.80 | 97.13 | 95.55 | 95.13 | 94.13 | 93.98 | 94.20 | 94.95 | 95.75 |
| 1885 | 95.86 | 95.79 | 95.44 | 97.98 | 99.10 | 96.90 | 95.91 | 95.35 | 95.38 | 95.46 | 97.29 | 97.26 | 96.48 |
| 1886 | 97.34 | 97.08 | 96.93 | 98.70 | 97.89 | 96.56 | 95.55 | 94.89 | 94.33 | 94.34 | 94.98 | 96.32 | 96.24 |
| 1887 | 95.64 | 96.84 | 96.31 | 98.86 | 99.87 | 97.95 | 96.41 | 95.44 | 94.69 | 94.08 | 93.97 | 95.37 | 96.29 |
| 1888 | 95.62 | 95.70 | 96.27 | 98.90 | 100.07 | 98.01 | 96.27 | 95.22 | 95.43 | 95.93 | 96.88 | 97.15 | 96.79 |
| 1889 | 97.91 | 97.14 | 96.63 | 98.12 | 97.97 | 97.48 | 96.91 | 96.26 | 95.35 | 95.86 | 96.62 | 96.82 | 96.87 |
| 1890 | 96.54 | 97.08 | 97.80 | 98.26 | 99.22 | 98.77 | 96.57 | 95.36 | 96.63 | 96.51 | 96.62 | 96.38 | 97.15 |
| 1891 | 96.21 | 97.08 | 98.80 | 99.81 | 98.73 | 96.63 | 95.44 | 94.93 | 94.66 | 94.11 | 94.00 | 94.63 | 96.25 |
| 1892 | 96.40 | 96.20 | 95.82 | 98.07 | 97.42 | 97.87 | 98.91 | 97.77 | 96.92 | 95.56 | 95.75 | 95.73 | 96.87 |
| 1893 | 95.00 | 94.83 | 95.37 | 97.15 | 98.46 | 97.03 | 95.39 | 94.87 | 95.96 | 95.04 | 94.40 | 94.49 | 95.67 |
| 1894 | 95.43 | 95.49 | 97.14 | 97.43 | 96.80 | 96.22 | 95.38 | 94.53 | 94.09 | 94.06 | 94.56 | 94.61 | 95.48 |
| 1895 | 94.81 | 94.70 | 94.73 | 97.51 | 98.36 | 96.63 | 95.26 | 94.76 | 94.63 | 94.10 | 94.50 | 96.17 | 95.51 |
| 1896 | 96.78 | 95.96 | 97.64 | 100.13 | 99.09 | 96.59 | 95.54 | 94.85 | 94.30 | 94.43 | 95.19 | 95.36 | 95.49 |
| 1897 | 94.97 | 94.84 | 95.62 | 98.43 | 99.08 | 98.49 | 97.92 | 97.70 | 96.11 | 95.04 | 95.41 | 96.96 | 96.71 |
| 1898 | 96.67 | 96.82 | 98.70 | 99.03 | 97.75 | 96.50 | 95.41 | 94.69 | 94.44 | 95.07 | 95.54 | 95.35 | 96.33 |

Mean elevation, 1875 to 1898, 96.10 feet.

*Monthly mean discharge of Lake Champlain, 1875 to 1898.*

[In cubic feet per second.]

| Year. | January. | February. | March. | April. | May. | June. | July. | August. | September. | October. | November. | December. | Discharge for mean stage. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1875 | 5,800 | 5,900 | 8,700 | 19,200 | 21,500 | 15,900 | 11,700 | 9,500 | 8,200 | 9,300 | 12,300 | 11,300 | 11,400 |
| 1876 | 14,400 | 13,900 | 16,100 | 22,700 | 30,400 | 20,700 | 13,900 | 9,400 | 6,600 | 6,000 | 5,700 | 5,000 | 13,205 |
| 1877 | 4,900 | 5,200 | 8,300 | 19,100 | 17,200 | 11,700 | 10,900 | 10,100 | 8,600 | 8,400 | 10,900 | 12,300 | 10,500 |
| 1878 | 10,400 | 8,700 | 12,000 | 19,300 | 21,200 | 13,800 | 10,100 | 13,100 | 12,700 | 8,600 | 9,300 | 17,800 | 13,000 |
| 1879 | 14,800 | 12,700 | 13,800 | 19,400 | 27,000 | 16,600 | 12,000 | 8,900 | 6,800 | 5,600 | 6,100 | 11,000 | 12,600 |
| 1880 | 11,300 | 14,000 | 15,900 | 17,100 | 15,800 | 11,400 | 8,500 | 6,300 | 4,400 | 3,840 | 9,100 | 8,300 | 10,400 |
| 1881 | 6,900 | 8,200 | 13,900 | 15,500 | 20,300 | 14,500 | 10,100 | 8,000 | 6,500 | 5,400 | 6,900 | 8,500 | 10,300 |
| 1882 | 12,100 | 11,500 | 16,800 | 15,600 | 14,700 | 17,200 | 13,800 | 9,700 | 7,600 | 7,200 | 5,500 | 4,400 | 11,200 |
| 1883 | 4,000 | 5,000 | 6,800 | 17,800 | 21,800 | 17,700 | 13,500 | 9,700 | 6,300 | 4,700 | 4,700 | 4,900 | 9,500 |
| 1884 | 5,300 | 8,700 | 14,900 | 25,300 | 23,400 | 16,100 | 10,300 | 8,900 | 5,500 | 5,400 | 5,700 | 8,300 | 11,000 |
| 1885 | 11,400 | 11,200 | 9,900 | 19,600 | 24,900 | 15,300 | 11,600 | 9,600 | 9,700 | 6,400 | 16,800 | 16,700 | 13,700 |
| 1886 | 17,000 | 16,000 | 15,400 | 22,900 | 19,200 | 13,900 | 10,300 | 8,100 | 6,200 | 6,200 | 8,400 | 13,100 | 12,800 |
| 1887 | 10,700 | 15,000 | 13,100 | 23,600 | 29,000 | 19,500 | 13,400 | 9,900 | 7,400 | 5,300 | 5,000 | 9,700 | 13,000 |
| 1888 | 10,600 | 10,900 | 12,900 | 23,900 | 30,200 | 19,700 | 12,900 | 9,200 | 9,300 | 11,700 | 15,200 | 16,200 | 15,000 |
| 1889 | 19,300 | 16,200 | 14,300 | 20,200 | 19,600 | 17,500 | 15,300 | 12,900 | 9,600 | 11,400 | 12,000 | 14,900 | 15,100 |
| 1890 | 13,900 | 16,000 | 18,800 | 20,800 | 25,500 | 23,200 | 14,000 | 9,700 | 14,200 | 13,800 | 14,200 | 13,300 | 16,200 |
| 1891 | 12,700 | 16,000 | 23,400 | 28,600 | 23,100 | 14,200 | 9,900 | 8,200 | 7,300 | 5,400 | 5,000 | 7,200 | 12,900 |
| 1892 | 13,400 | 12,700 | 11,300 | 20,000 | 17,300 | 19,100 | 23,900 | 18,700 | 15,300 | 10,400 | 11,000 | 11,000 | 15,100 |
| 1893 | 8,400 | 7,900 | 9,700 | 16,200 | 21,700 | 15,800 | 9,800 | 8,000 | 11,800 | 8,500 | 6,600 | 6,700 | 10,800 |
| 1894 | 9,900 | 10,100 | 16,200 | 17,300 | 14,900 | 12,800 | 9,800 | 6,900 | 5,300 | 5,200 | 6,900 | 7,100 | 10,100 |
| 1895 | 7,800 | 7,400 | 7,600 | 17,600 | 21,300 | 14,200 | 9,400 | 7,600 | 7,200 | 5,100 | 6,700 | 12,500 | 10,200 |
| 1896 | 14,800 | 11,800 | 18,000 | 30,500 | 24,900 | 14,100 | 10,300 | 7,900 | 6,100 | 6,500 | 9,100 | 9,700 | 10,100 |
| 1897 | 8,300 | 7,900 | 10,600 | 21,600 | 24,800 | 21,900 | 19,300 | 18,400 | 12,300 | 8,500 | 9,800 | 15,400 | 14,500 |
| 1898 | 14,400 | 14,900 | 22,900 | 24,500 | 18,600 | 13,800 | 9,800 | 7,400 | 6,500 | 8,760 | 10,300 | 9,600 | 13,200 |
| Sum | 262,500 | 267,800 | 331,300 | 498,300 | 528,300 | 380,600 | 294,500 | 236,100 | 202,000 | 177,300 | 213,200 | 255,900 | 295,800 |
| Mean | 10,937 | 11,158 | 13,804 | 20,762 | 22,012 | 16,275 | 12,271 | 9,837 | 8,416 | 7,387 | 8,883 | 10,662 | 12,325 |

Mean discharge, 1875 to 1898, 12,700 cubic feet.

*Mean monthly storage and supply to Lake Champlain, 1875 to 1898.*

| Year | February. | | | March. | | | April. | | | May. | | | June. | | | July. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Rise. | Storage. | Supply. | Rise. | Storage. | Supply. | Rise. | Storage. | Supply. | Rise. | Storage. | Supply. | Rise. | Storage. | Supply. | Rise. | Storage. | Supply. |
| | *Feet.* | *Cu. ft. per sec.* | *Cu. ft. per sec.* | *Feet.* | *Cu. ft. per sec.* | *Cu. ft. per sec.* | *Feet.* | *Cu. ft. per sec.* | *Cu. ft. per sec.* | *Feet.* | *Cu. ft. per sec.* | *Cu. ft. per sec.* | *Feet.* | *Cu. ft. per sec.* | *Cu. ft. per sec.* | *Feet.* | *Cu. ft. per sec.* | *Cu. ft. per sec.* |
| 1875 | 0.02 | 93 | 5,993 | 0.85 | 3,937 | 12,637 | 2.79 | 12,924 | 32,224 | 0.53 | 2,456 | 23,956 | | | | | | |
| 1876 | | | | 0.55 | 2,548 | 18,648 | 1.55 | 7,180 | 29,880 | 1.45 | 6,716 | 37,116 | | | | | | |
| 1877 | | | | 0.91 | 4,215 | 12,515 | 2.89 | 13,386 | 32,486 | | | | | | | | | |
| 1878 | | | | 0.98 | 4,535 | 16,535 | 1.88 | 8,716 | 28,016 | 0 42 | 1,956 | 23,156 | | | | | | |
| 1879 | | | | 0.31 | 1,436 | 15,236 | 1.43 | 6,624 | 26,024 | 1.56 | 4,891 | 31,891 | | | | | | |
| 1880 | 0.73 | 3,382 | 17,382 | 0.50 | 2,316 | 18,216 | 0.32 | 1,482 | 18,582 | | | | | | | | | |
| 1881 | 0.40 | 1,853 | 1,033 | 1.62 | 7,501 | 21,404 | 0 40 | 1,853 | 17,353 | 0.17 | 788 | 22,088 | | | | | | |
| 1882 | | | | 0.43 | 1,991 | 18,791 | 0.30 | 1,390 | 13,210 | −0.24 | 1,111 | 13,589 | +0.63 | 2,918 | 20,118 | | | |
| 1883 | 0.30 | 1,390 | 6,390 | 0.52 | 2,409 | 9,209 | 3.03 | 14,035 | 31,835 | 0.93 | 4,308 | 26,108 | | | | | | |
| 1884 | 1.00 | 4,632 | 13,332 | 1.72 | 7,968 | 22,868 | 2.38 | 11,022 | 36,322 | | | | | | | | | |
| 1885 | | | | | | | 2.54 | 11,761 | 31,361 | 1.12 | 5,188 | 30,088 | | | | | | |
| 1886 | | | | | | | 1.87 | 8,662 | 31,562 | | | | | | | | | |
| 1887 | 0.20 | 926 | 15,926 | 0.53 | 2,455 | 10,645 | 2.55 | 11,812 | 35,412 | 1.01 | 4,678 | 33,678 | | | | | | |
| 1888 | 0.08 | 370 | 11,270 | 0.57 | 2,640 | 15,340 | 2.63 | 12,182 | 36,082 | 1.17 | 5,419 | 35,619 | | | | | | |
| 1889 | | | | | | | 1.49 | 6,902 | 27,102 | | | | | | | | | |
| 1890 | 0.54 | 2,501 | 18,501 | 0.72 | 3,336 | 22,136 | 0.46 | 2,131 | 22,931 | 0.96 | 4,447 | 29,947 | | | | | | |
| 1891 | 0.87 | 4,030 | 20,300 | 1.72 | 7,968 | 31,368 | 1.01 | 4,678 | 33,278 | | | | | | | | | |
| 1892 | | | | | | | 2.25 | 10,422 | 30,422 | 0.65 | 3,011 | 14,289 | +0.47 | 2,177 | 21,277 | 1 04 | 4,817 | 28,717 |
| 1893 | | | | 0.54 | 2,501 | 12,201 | 1.78 | 8,246 | 24,446 | 1.31 | 6,068 | 27,768 | | | | | | |
| 1894 | 0.06 | 278 | 10,378 | 1.65 | 7,643 | 25,843 | 0.29 | 1,343 | 18,643 | | | | | | | | | |
| 1895 | | | | 0.03 | 139 | 7,739 | 2.78 | 12,878 | 30,478 | 0.85 | 3,937 | 25,237 | | | | | | |
| 1896 | | | | 1 68 | 7,782 | 25,782 | 2.49 | 11,534 | 42,034 | | | | | | | | | |
| 1897 | | | | 0.78 | 3,614 | 14,314 | 2.81 | 13,016 | 31,616 | 0.65 | 3,011 | 27,811 | | | | | | |
| 1898 | 0.15 | 695 | 15,595 | 1.88 | 8,716 | 31,616 | 0.33 | 1,529 | 26,029 | | | | | | | | | |

The watershed of the lake has an area of 7,750 square miles, on which the average precipitation is about 33 inches per year.

| | Cubic feet per second. |
|---|---|
| Mean discharge of Richelieu River | 12,700 |
| Evaporation from lake in 8 months = 1.25 feet | 724 |
| Total | 13,424 |
| One foot storage in lake = 386. | |
| Average rainfall on lake = 386 × 2.75 | 1,061 |
| Average run off from watershed | 12,363 |
| Average run off = 65 per cent of the precipitation. | |

The discharge for an elevation of 101 feet is about 36,000 cubic feet per second, or equivalent to the maximum supply to the lake. The lake has not exceeded this elevation since 1875 except when affected by wind, and the mean monthly supply has exceeded the corresponding discharge only once (April, 1896). The rapid rise of April, 1896, is thought to have been abnormal and due to ice in the Richelieu River diminishing the flow and thereby indicating a greater supply than actually existed.

During low-water years the lake level falls to an elevation of about 94 feet above tide water in September and October, with a discharge of about 5,000 cubic feet per second; and since the power companies on the Richelieu River are entitled to the full value of the natural low-water discharge, any diminution produced either by regulation or use of feed water for the Hudson River Canal must be made good by an equivalent supply from the St. Lawrence River through the canal from Lake St. Francis to Lake Champlain. This supply will not exceed 1,500 cubic feet per second, or about one-fourth of a foot per second velocity in the canal.

In order to maintain the low-water level of Lake Champlain at or above elevation of 100 feet above tide water, regulating works will have to be constructed near the foot of the lake capable of passing the maximum supply to the lake at times of high water and of maintaining the discharge at about 5,000 cubic feet per second during the usual low-water period in the fall of the year.

Two different projects have been proposed for this purpose, viz:

First. To construct a dam 5,000 feet long between Stony Point and Windmill Point, with a lock and regulating sluices at Stony Point, about 1.5 miles south of Rouse Point, the crest of the dam to be at an elevation of 99.5 feet, and the sluices of sufficient capacity to pass 5,000 cubic feet per second when the lake level is at an elevation of 100 feet above tide water; or,

Second. To construct a dam with crest above the high-water stage of the lake, and sluices at Stony Point of such dimensions that when all are open the entire volume of maximum supply may be passed.

With the first of these plans, the discharge when the lake is at a stage of 100 feet will be approximately $5{,}000 \times 2.8 \times (0.5)^{\frac{3}{2}} = 5{,}000$ cubic feet per second; and for a stage of 101.5 feet above tide water the discharge will be $5{,}000 \times 2.7 \times (2)^{\frac{3}{2}} = 38{,}000$ cubic feet per second, or practically the maximum supply to the lake during the greatest rise of the lake since 1871.

The change of the lake level at the regulating works from wind effect and the consequent fluctuations of the discharge through the Richelieu River will be a serious objection to the use of a long submerged dam for the purpose of controlling the lake level. If the dam be built up to the elevation of high-water stage, and a sufficient number of sluices constructed to pass the discharge at times of maximum supply, the flow can be controlled at all times and the reservoir capacity of the lake, due to change of level, utilized so as to maintain a greater low-water discharge than under natural conditions.

The elevation of the lake at Fort Montgomery for a discharge equivalent to the maximum supply to the lake is about 101 feet above tide water; and as the head required to produce and maintain flow through the sluices will be about 0.75 foot, the high-water stage of the lake will be between 101.5 and 102 feet above tide water, or a range of the lake level of less than 2 feet, when not affected by the wind.

At the site of the proposed dam rock crops out at the water surface at Stony Point, and at 500 feet from the shore is 20 feet below the proposed plane for regulated stage of the lake, making a favorable location for a lock and for foundation for piers and sills of sluice gates.

If these sluices be made 20 feet deep, with an aggregate width of 300 feet, a head of about 0.75 foot will be required to pass the discharge at times of maximum supply to the lake. Such a system of sluices, with a high dam for the control of the lake level, will be more expensive than a long submerged weir with a single sluice, but the more complete control of the discharge which can be obtained by the use of the former is of sufficient importance to warrant its adoption and construction. A lock 300 feet long, 60 feet wide, 14 feet deep on the miter sills, with lift varying from 1 to 7 feet, depending upon the stage of water, has been estimated for in connection with the regulating dam and sluices.

The maximum volume of water needed for feeding the Hudson River division of the Champlain route will not exceed 1,200 cubic feet per second, and for a large portion of the season will be much less. At times of high water in the Hudson River the water in the river at Fort Edward will be higher than in Lake Champlain at Whitehall, and, if desirable, a portion of the Hudson River flood may be diverted into Lake Champlain through the canal. Guard locks have been estimated for on this section of the waterway, so that the flow in either direction may be controlled as desired.

The details of estimate for regulating works and lock are as follows:

| | |
|---|---|
| Excavation in lake | 889,223 |
| Embankment | 12,188 |
| Timber crib dam | 390,434 |
| Sluice gates, piers, and operating plant | 122,300 |
| Lock | 276,099 |
| | 890,244 |
| Engineering, superintendence, and contingencies, 10 per cent | 89,024 |
| Total | 979,268 |

Respectfully submitted.

GEO. Y. WISNER.

THE BOARD OF ENGINEERS ON DEEP WATERWAYS.

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APPENDIX NO. 9.—PART 1.

## INSTRUCTIONS FROM SECRETARY OF WAR FOR THE GUIDANCE OF THE BOARD OF ENGINEERS ON DEEP WATRWAYS.

ORDERS.] WAR DEPARTMENT,

*Washington, October 20, 1897.*

The orders of August 31, 1897, promulgating instructions for the guidance of the Deep Waterways Board, designated and appointed by the President under the provisions of the sundry civil appropriation act approved June 4, 1897, are hereby amended and enlarged so as to read as follows:

Par. 1. The said Board is authorized to rent such necessary office rooms (except in the city of Washington) and, when the exigencies of the service will not admit of advertisement and contract, to purchase in open market such materials, including instruments, books, maps, field outfits, provisions, and other supplies of any kind, as in its judgment are deemed necessary for the prosecution of its work, and to employ such assistance as it may deem essential, and to pay such reasonable compensation therefor as it may deem proper, the expenses for all purposes not to exceed the amount appropriated, viz, $150,000.

Par. 2. The secretary to the Board, James H. Kidd, is hereby designated as special disbursing agent to disburse the appropriation in addition to his duties as secretary. He will make requests on the Secretary of War for funds as they may be needed from time to time, said requests to be approved by the president of the commission, and in forwarding the same will name some United States depositary in which he wishes the funds placed, and state the address to which he desires the notification to be sent to him from the Treasury Department. He will account for all expenditures, as well as for all property, under the orders and supervision of the Board, and will give bond in the sum of $25,000 for the faithful execution of these duties. An

itemized account of all disbursements, with proper vouchers, will be transmitted monthly to the War Department for approval and transmitted to the Auditor for settlement.

Par. 3. The Board shall authorize and supervise all disbursements, and the power to approve the accounts of the disbursing officer, so far as relates to the necessity or expediency of the expenditure, and the prices paid, is hereby delegated to the president of the Board, and such approval by him shall be final in the War Department. The approval of the Board by the president shall be indorsed on the account current.

Par. 4. Journeys may be made by any member of the Board whenever necessary for the public service, subject to subsequent approval by the Board. Journeys to be performed by the employees of the Board may be ordered by any member of the Board. When the emergency requiring the journey does not permit of obtaining an order previous to making the journey, the employee must certify upon the expense voucher "that urgent public duty required the journey to be performed without previous orders." All journeys must be finally approved by the Board, and the vouchers must be accompanied by that approval. Through tickets must be obtained for all travel when the journeys are to be continuous, and transportation requests used whenever practicable.

Par. 5. All vouchers in payment for articles or materials shall have attached to them the original receipted bill or bills for the articles or materials, said bills to be furnished by the person, firm, or corporation supplying them.

Par. 6. The following reports and returns shall be made on the forms of the Corps of Engineers, United States Army, or other form authorized by the War Department, and transmitted by the disbursing officer to the Secretary of War within ten days after the expiration of the month or quarter to which they relate, except Form 13, which will be rendered within twenty days after the expiration of the quarter, Form 17, which will be rendered at the close of business hours of each week, and Form 14, which will be rendered at the close of the month, viz:

(1) Weekly Money Statement, Form 17.

(2) Monthly Money Statement, Form 14.

(3) Monthly Account Current, in duplicate, Form 3.

(4) Monthly Abstract of Disbursements, in duplicate (Forms 4, 5, or $5^a$), with proper vouchers (Forms 6, 7, 8, $8^a$, 9, $9^a$, 10, 11, 12, 22, 23).

(5) Quarterly Return of Public Property Received and Expended, Forms $13^1$, $13^2$, $13^3$, and $13^a$.

Par 7. All officers, agents, or other persons who are charged with the safe-keeping, transfer, or disbursement of the public moneys shall keep an accurate entry of each payment or transfer, and shall

render distinct accounts of the application thereof according to the appropriation under which the moneys may have been advanced to them. Every officer or agent who, having received public money which he is not authorized to retain as salary, pay, or emolument, fails to render his accounts for the same, shall be deemed guilty of embezzlement, and shall be fined in a sum equal to the amount of the money embezzled, and shall be imprisoned not less than six months nor more than ten years. (R. S., 3623, 3643, 5491.)

Par. 8. An error made in an account must be corrected in the next account current of the disbursing officer after he is informed of the error, and reference will be made therein to the particular voucher in which the error occurred.

Par. 9. Funds received from overpayments previously made will be entered on the account current in the proper column. The entries should show by whom and to whom the overpayments were made and on what account, and refer to the voucher and abstract.

Par. 10. Whenever money is refunded to the Treasury, the name of the person refunding and the purpose for which it was done must be stated.

Par. 11. The disbursing officer will promptly, at the close of business at the end of each month, and also on Saturday of each week, when that month does not end on Saturday, transmit to the War Department a statement showing explicitly where his funds are deposited. He will include in the sums claimed to be on deposit only such funds as have been officially credited to him, and of which credit he has been duly informed by the depositary. All public funds on deposit must be to the official credit of the disbursing officer.

Par. 12. Disbursing officers have no authority to insure public money or property. They are not authorized to settle with attorneys of claimants, heirs, executors, or administrators, except by instructions from the War Department upon accounts duly audited and certified by the proper accounting officers of the Treasury. (Sec. 3477, Rev. Stat.)

Par. 13. All payments by the disbursing officer must be made in checks upon his deposit in a public depositary, in lawful coin, or in United States notes. Payments, whenever possible, shall be made within the quarter in which the liability was incurred.

Par. 14. When funds are available, the disbursing officer shall pay cash and not open an account.

Par. 15. When the disbursing officer draws checks in payment of accounts, on funds placed to his credit with an assistant treasurer or other depositary of the United States, he will note upon the receipt taken for such payment the number, date, and amount of the check given in payment and designate the assistant treasurer or depositary upon whom it is drawn; and when an account is paid in part by currency, the amount of the same will be stated. The same rule will be observed in regard to invoices of funds transferred. Mutilated checks

shall at once be forwarded to the depositary to which they pertain, and a record made on the stubs of the check book of the date of transmission.

Par. 16. In all cases of contracts for the performance of any service or the delivery of articles of any description for the use of the United States, payment shall not exceed the value of the service rendered or of the articles delivered previous to the payment.

Par. 17. Persons employed in the service of the Board may be allowed actual expenses for travel on duty under orders. For all persons except the members of the Board and its secretary, and military and naval officers, these expenses will be limited as follows:

(1) Cost of transportation (including parlor-car fare) over the shortest usually traveled route.

(2) Cost of transfers to and from railroad stations, not exceeding 50 cents for each transfer.

(3) Cost of one double berth in a sleeping car, or customary stateroom accomodation on boats and steamers when extra charge is made therefor.

(4) Cost of meals, not exceeding $3 per day while en route, when meals are not included in the transportation fare paid, and not exceeding $3 per day for meals and lodgings during necessary delay en route.

(5) Cost of meals and lodgings, not exceeding $3 per day, while on duty at places designated in the orders for the performance of temporary duty.

When such expenses are less than $25 under any given order, the certificate of the person performing the journey, as set forth in Form 9, will be sufficient; when the expenses are $25 or over, the affidavit of the person will be required, as follows:

I, ——— ———, solemnly swear that the above account is correct and just, and that I necessarily performed the above journey on public business, at the time specified, with all practicable dispatch, by the shortest usually traveled route, in the customary reasonable manner, and under the order hereto annexed; that I did not travel on any conveyance belonging to or chartered by the United States; that the above expenses were actually and necessarily incurred and paid by me in performing said journey.

Sworn to before me and subscribed in my presence this —— day of ———.

———— ————.

———— ————.

The legal fee for the same may be included in the account. In all cases there should be added the certificate of a member of the Board approving the account and certifying that the travel was performed under the orders specified in the voucher.

Par. 18. No member or employee of the Board shall accept voluntary service for the Government, or employ personal service in excess of that authorized by law, except in cases of sudden emergency, involving the loss of human life or the destruction of property.

Par. 19. The time of all employees noted or kept as hours shall be reduced to "days of eight hours each," and the rate of pay shall be noted and designated as the rate "per day of eight hours each," and so shown upon the vouchers or pay rolls, as the case may be. Time employed should not be shown upon the pay rolls or vouchers in "hours," and the rate of pay should not be designated as "per hour."

When pay rolls or vouchers show persons to have been employed and paid by the day, there should be added to the certificate the statement that the days for which payment has been made were "days of eight hours each."

Par. 20. When it is intended to have any work done, service procured, or purchase made, by contract or written agreement, all the papers in the case must previously be submitted to the Board for its approval.

Par. 21. Where it is clearly for the benefit of the United States that a contract should be extended, power is hereby delegated to the Board to grant such extension, but extensions of contracts or written agreements are not in any case to be made until the approval of the Board has been obtained.

Par. 22. Vouchers for the disbursement of money will correctly specify the quantity and price of each article bought, the name and business place of the person from whom it is procured, and the date and manner of purchase. When the vouchers are for services rendered, they will state the nature and period of service, rate of pay per day or month, etc.

Par. 23. Original vouchers must accompany the accounts. Copies can not be admitted unless accompanied by satisfactory evidence of the loss or destruction of the originals, or that their retention is indispensable to the performance of duty.

Par. 24. When originals can not be furnished, copies duly certified as true by a disinterested officer of the Government may be accepted.

Par. 25. When vouchers are not sent with the account to which they belong, an explanation must be made as to why they were not produced with and included in the proper account.

Par. 26. All employees of the Board are forbidden to give or take receipts in blank for public money or property; in all cases the voucher will be made out in full and the exact amount of money or quantity of property, in words, will be written out in the receipt before it is signed. When vouchers are sent by mail for signature, the date in the receipt will be left blank, and the check in payment will not be drawn until the vouchers are received back properly signed, when the date of the check will be added to the receipt.

Par. 27. When a signature is not written by the hand of the party it must be witnessed.

Par. 28. When an account is presented in person by an individual who is not known to the disbursing officer, the latter will require such

evidence of identity as will secure the Government as well as himself against loss.

Par. 29. Upon all vouchers for purchases or for services other than personal, the method of purchase, or of procuring the service, must be shown, and if "by written agreement," a copy of the agreement must accompany the voucher.

Par. 30. Property returns will be rendered quarterly. After a complete return has been furnished, if there have been but few changes during a subsequent quarter, it will be sufficient for three quarters to state these changes.

Par. 31. At the time when vouchers are submitted with the accounts, if any of the articles purchased as noted thereon have been "expended and applied to the purpose for which purchased," a certificate to that effect may be made by the disbursing officer on the voucher, and when so made the article referred to need not be taken up on the property returns.

Par. 32. The certificate of an authorized agent of the Board of the delivery of supplies or materials, or of the performance of service, shall constitute authority to the disbursing officer for payment therefor; but should the facts not be as set forth in said certificate, the amount shall be charged to the certifying agent and be credited to the disbursing officer in the settlement of his accounts.

Par. 33. No member or employee of the Board shall be pecuniarily interested, either directly or indirectly, in the employment of any person, or the purchase or supply of any article or materials for the service of the Board.

Par. 34. All persons having charge of property pertaining to the Board shall be held responsible for its preservation and safe-keeping, and shall give receipts to the disbursing officer for the same. They are required to take all proper measures to protect it from loss, damage, or waste; and when such property is not satisfactorily accounted for, the person to whom it was intrusted shall be charged with its value.

Par. 35. In all cases not covered by these regulations, the rules for money and property accountability established in the United States Army Regulations of 1895, so far as applicable to the service of the Board, shall be observed.

Par. 36. The instructions to United States disbursing officers contained in circular from the Treasury Department dated August 14, 1897, and published in General Orders, No. 53, War Department, Adjutant-General's Office, August 25, 1897, must be strictly complied with.

R. A. ALGER,
*Secretary of War.*

## Appendix No. 9.—Part 2.

### INSTRUCTIONS TO FIELD PARTIES.

The following instructions are for the general guidance of field parties, and will be supplemented from time to time by such special instructions from the Board as may be found necessary as the work progresses.

The immediate object of the work is to obtain data for the development of plans, estimation of cost, and the construction of maps and profiles of the proposed ship canal from the Great Lakes to the Atlantic.

Considerable discretion will be allowed chiefs of parties as to methods by which information sought shall be obtained and the distribution of work among members of the party, but the records of all surveys and examinations must be so full and complete that they may be easily and correctly interpreted by computers in the office of the Board without assistance from the engineers who make the observations.

The work must be such that when reduced and plotted a paper location may be made of the proposed ship canal, a correct estimate made of the amount and kind of material which will need to be excauated, and the size and character of all necessary structures projected.

#### ORGANIZATION.

The personnel of the parties herein outlined is based on normal conditions of country, a full-sized field party consisting of a base-line party, level party, sounding party (where needed), two or three boring parties, three stadia parties, and draftsman and computers sufficient to keep up reduction and plotting of field notes as close as practicable with the field work. All parties are to work with the general purpose in view that the combined results of the different divisions should be sufficient to furnish the necessary data on which to base designs, plans, and estimates of proposed ship canal route, and in order that the best progress for amount of work done shall be obtained it is essential that the parties should not duplicate their own work or that of others, except where necessary for correcting errors.

Each of the stadia parties should consist of 1 instrument man, 1 recorder, 2 rodmen, and 1 stadia man for open country, and such axmen as may be needed to cut lines where topography of wooded country is to be determined. In organizing new parties, recorders and rodsmen, where capable, should always be promoted in preference to appointing new men.

#### METHODS OF WORK.

*Reconnoissance.*—A careful reconnoissance should be made of the proposed line of survey by the assistant engineer in charge in advance of all field work, to determine the limits of survey and the probable

location of right of way along which it will be necessary to determine contours carefully, and make borings sufficient to establish the elevation of rock surface, where it exists within limits of probable depth of cut.

*Topography.*—The topography will be based on continuous transit and level lines between terminals of any section of the proposed canal, and be determined by stadia readings from the stations and bench marks of said lines to all characteristic points.

Topography will be taken with the view of correctly plotting contours for 2-foot intervals along right of ways, but outside of such limit slight irregularities of the surface are of no importance, and only elevations of characteristic points should be taken by the stadia men, and sketches made between.

Base line and level observations, where possible, should be kept in the advance of topographical work, and the elevations and location of transit stations, with azimuth of line, furnished to the stadia parties.

*Transit lines.*—The distances between transit points of main line should be measured with a steel tape of which the length has been determined by actual measurement of a base line of known length, or by comparison with some standard measure already determined, and such distances checked by intersections on known points or by stadia readings of the topographical parties.

The true azimuth of the survey line should be determined at intervals of about 5 miles along the route, by observation on elongation of Polaris, for the purpose of correcting the transit line for errors of observation and for change in azimuth due to convergence of meridians. To determine the azimuth of a line from observations of Polaris at elongation, a set of readings should be made between the star and reference mark, and the telescope should then be reversed and a second set made.

The difference between the observed azimuth at any station and that brought forward from previous station by transit line is always equal to the algebraic sum of the errors of observations and the change due to the convergence of meridians. The latter of these two corrections should be distributed back through the transit stations proportionately to the respective westings, and the former proportionately to the number of transit stations between azimuth stations. In order, therefore, that all corrections be properly applied, there should be an azimuth determination of transit line in advance of all work plotted on office map.

Permanent marks as reference points will be established by the transit and level parties at frequent intervals along the line, such that any paper location made upon the maps may be easily and correctly staked out on the ground surveyed.

*Levels.*—The elevations of all bench marks of level lines will be based, wherever possible, on the elevation of bench marks established by precise level parties of the United States Lake Survey, and, unless

checked by readings on points of known elevations, should be determined by duplicate lines run in opposite directions.

Duplicate level lines must agree within the amount shown by the formula $\frac{5}{100}\sqrt{\text{distance between bench marks in miles.}}$

Frequent readings should be made for connecting with the water surfaces, wherever the lines run are in the immediate vicinity of lakes, rivers, or canals.

*Methods of stadia work.*—Stadia parties should be furnished with corrected azimuths of transit line, and all stadia circuits should be carried forward from such initial directions and checked on other lines of known azimuth wherever possible. Where this can not be done, the magnetic azimuth of lines should be read occasionally, and readings made to prominent points on the line of survey, the location of which may be independently determined. In stadia circuits, stakes need be set only at instrument stations, and at points where side lines are to be started for closures made with other circuits.

Where areas of timber land and orchards interfere with lines of sights, contours may be developed sufficiently well by determining cross profiles at intervals by stadia readings along compass line.

No matter which member of the party may make the observations, it should be distinctly understood that he should make the complete readings, both as to direction and distance, and no other person be allowed near the instrument.

The instrument man and recorder should make the observations, keep the records, and make sketches, except where the conditions are such that only two rodmen are needed, in which case the extra rodman may be detailed to sketch or make reconnoissance for advance work.

In addition to readings to develop contours, all buildings, fences, roads, creeks, culverts, bridges, timber lands, etc., should be located, and where structures are on line of probable final location, the dimensions and character should be noted. Highways, fences, railroads, streams, and embankments should be located by readings to points where directions change, and a sketch made showing connection between consecutive points. Where rivers are to be sounded, all range stakes should be set in advance by either the transit or stadia field parties.

The width, depth, and cross-section of streams for high, low, and medium stages should be determined wherever possible. The limit of work for survey should be determined by reducing side shots in the field, and not by running special circuits along lines of elevation required.

The instrument man should have a system of signals for his party, such that he may direct a rodman in any direction, and to make any kind of location desired.

In all cases the work should be so planned that stations need not be

reoccupied, except to start new lines or to correct errors, and that work done by other divisions of the main party will not be duplicated.

Where possible to do so, the stadia party should leave stakes for boring party to connect with when holes are drilled, and thus save labor of locating holes after work is done. Stadia parties in the field need do only sufficient plotting to insure that records are free from error and that sufficient locations have been made to develop the topography.

*Borings.*—Borings will be made at such intervals and depths along the lines that the location, amount, and kind of material to be excavated may be accurately estimated for a ship canal of 30 feet depth located within the limits of strip surveyed.

*Reduction of notes.*—The field party should keep their notes reduced up to date and ready for checking by the computers in office of engineer in charge.

All notes, records, and sketches should be so clear and complete that no misinterpretation can occur.

## PLOTTING OF FIELD NOTES.

In the office of assistant engineer in charge of party there should be a draftsman and sufficient computers to reduce and plot the field notes as fast as sent in by the stadia parties.

The computers should be men capable of reducing field notes and assisting the draftsman in plotting preliminary lines and circuits on maps. Maps should be on a scale of 1:2,500 or 1:5,000, depending on the flatness of the country, and should be drawn on mounted paper 28 by 40.5 inches in size, with working limits of 25 by 37 inches, and laid out so as to have a wide margin at left-hand end of completed map. All lines, fences, roads, etc., should be plotted with india ink and all contours with burnt sienna.

Transit lines and important stadia circuits should be plotted by coordinates, and side lines and readings by direction and distance. For small vertical angles no reduction for distance is necessary for side shots, and for main circuits the correction may be taken direct from a table prepared for that purpose.

Transit line distances should be corrected for tape error and temperature before plotting.

Only such lettering need be put on maps as necessary for a correct interpretation, and no azimuth of courses except line indicating the true meridian through some azimuth or transit station.

All work to be plain and accurate, and of a style to be rapidly done.

## FINISHING FIELD SHEETS AND REDUCTION.

The finishing of field maps not provided for in these instructions and the reduction for publication will be done at the office in Detroit.

All maps for publication are to be reduced to a scale of 1:20,000 by means of a pantograph, such reduced sheets to show the amount of

detail to be put on tracings, except that swamp and timber areas will be indicated with topographical symbols, and where slopes are steep hachures will be used instead of contours. Where wood and swamp areas are large, only the limits need be indicated by symbols. The line of proposed waterway will be indicated by two parallel lines spaced 250 feet apart, except in open rivers and lakes, where actual width estimated will be shown.

Location and depth of borings will be indicated by showing elevation of bottom of hole, and if rock be found, such number will be followed by the letter R.

The projected line will be marked every 1,000 feet and at every mile on the map, and a profile of the line marked to correspond with that on map will be placed at bottom of the sheet.

### REPORTS.

A weekly report should be made at the end of each calendar week, giving briefly the amount of work done and any other information of interest or importance.

A monthly report should be made promptly at the close of each month, giving a detailed statement of work done, condition of work or works in progress at that date, and other important information or suggestions.

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## APPENDIX NO. 10.

### NIAGARA ROUTE AND CHAMPLAIN ROUTE, HUDSON RIVER DIVISION—FLOOD MEASUREMENTS MOHAWK RIVER—LEVELS FROM HUDSON RIVER TO LAKE ONTARIO.

DETROIT, MICH., *January 15, 1900.*

GENTLEMEN: I have the honor to report herewith on the surveys and examinations intrusted to me in connection with the proposed deep waterway from the lakes to the Atlantic. The report is arranged under the following headings:

1. A waterway from Lake Erie to Lake Ontario of 21 feet and 30 feet depths.
2. A waterway from Lake Champlain to the Hudson River at Troy of 21 feet and 30 feet depths.
3. Flood-discharge measurements of the Upper Mohawk River and other streams.
4. Report on results of two lines of levels run from the Greenbush bench mark to Lake Ontario.

The above work, excepting item 4, was executed by one organization, made up in Chicago between August 17 and September 12, 1897, with such additions, from time to time, as the necessities of the work required. After purchasing and testing instruments, the party left

Chicago September 12, 1897, and arrived at Tonawanda, N. Y., the next day, and immediately began the surveys for the Tonawanda-Olcott route. The order in which the other work was done is fully explained in the reports covering it.

I wish to acknowledge receipt of valuable information relating to the hydrography of the Hudson River, from the Glens Falls Paper Company, of Fort Edward, N. Y.; the Duncan Company, of Mechanicville, N. Y.; the Hudson River Power Transmission Company, of Mechanicville, N. Y., and Mr. Frederick Orr, of Troy, N. Y. Mr. E. A. Bond, State engineer and surveyor of New York, permitted me to consult the original maps and notes of the survey made of the Hudson River in 1866, from which valuable information was obtained.

To the great application and thorough work of the instrument men in charge of parties, P. H. Ashmead, J. H. Brace, H. F. Dose, H. C. Goodrich, Curtis Hill, T. J. Klossowski, and W. George Lee, and the superintendent of borings, George A. Hammond, much of the progress of the work is due. Mention should also be made of H. H. Letter and M. W. Tenny, instrument men; A. A. Conger, M. K. Trumbull, and E. J. Kelly, recorders, who rendered valuable assistance in the office at Detroit as well as in the field. Those in positions of less responsibility were equally faithful and energetic in the performance of the duties assigned them. A list of all the men employed, with length of service of each, is filed with the secretary of the Board.

The instructions of your honorable Board gave me great freedom in the selection of assistants for the various positions, and resulted in building up the best force it has ever been my good fortune to secure, and in establishing an esprit de corps not otherwise obtainable.

Respectfully submitted.

C. L. HARRISON.
*Principal Assistant Engineer.*

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

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## WATERWAY FROM LAKE ERIE TO LAKE ONTARIO, EMBRACING THE TONAWANDA-OLCOTT AND LASALLE-LEWISTON ROUTES.

Two possible routes were considered, both beginning at deep water in Lake Erie, near Buffalo, and running through Black Rock Harbor and the Erie Canal to near the head of Squaw Island; then locking down to the level of the Niagara River, and following the general course of its right branch to a point just above Tonawanda, where the routes separate. One passes through Tonawanda and via Lockport to Lake Ontario at Olcott. This is designated as the Tonawanda-Olcott route. The other route continues down the Niagara River from Tonawanda to the head of Cayuga Island, near the village of Lasalle, and thence across the country in a northwesterly direction

to the Niagara River at the village of Lewiston, and thence down the river to Lake Ontario. This is designated as the Lasalle-Lewiston route.

SURVEYS.

The two routes being identical from Lake Erie to Tonawanda, and then passing through similar territory, the surveys and examinations will be considered as of one project, especially as the work was being done on both routes at the same time.

The following parts of the line were surveyed by this party:

Surveys and borings from the breakwater in Lake Erie to the foot of Squaw Island, including soundings at site of Regulating Works; from Tonawanda to and including the Olcott Harbor; from Lasalle to Lewiston.

The following parts of these routes were surveyed by James Ritchie, assistant engineer:

Soundings and borings at foot of Lake Erie and outside of breakwater; soundings in Niagara River, from the foot of Squaw Island to Tonawanda; borings in Niagara River, from foot of Squaw Island to Lasalle.

The soundings in the Niagara River from Tonawanda to Lasalle were taken from the survey made in 1896, under the direction of Maj. Thomas W. Symons, Corps of Engineers, U. S. Army.

The soundings in the Niagara River from Lewiston to its mouth, and to deep water in Lake Ontario, were taken from the lake-survey charts of 1875. But a few borings and soundings were taken, June, 1899, on the shoal off the mouth of the Niagara River, to determine the character of material to be excavated and what changes have taken place since the survey of 1875.

In general, all surveys were made in accordance with the instructions of the Board as given in Appendix No. 9.

The base lines were chained with a standardized steel tape, using spring balance to insure uniform tension, and correcting for temperature. Observations were made for azimuth about every 5 miles. Topography of the adjacent territory was taken by stadia, sufficient points being taken to develop 2-foot contours. Stadia circuits started from a known point on the base line and closed on another such known point. All elevations are referred to the bench mark on the lighthouse at Buffalo. The elevation of this bench mark as determined by the lake survey, partly by spirit levels and partly by water levels, starting from the Greenbush bench mark 14.73, is 589.807 feet above mean tide at New York.

A duplicate line of levels was run—using wye level and New York rods—from this bench mark along the right bank of the Niagara River, via Tonawanda and Lasalle, to the power house of the Cataract Construction Company at Niagara Falls. Starting from bench marks

FIG. NO. 1.

BORING APPARATUS.

on this line duplicate lines of levels were run from Tonawanda to Olcott and from Lasalle to Lewiston, and permanent bench marks established at frequent intervals. At each point where observations for azimuth were made a monument was planted.

BORINGS.

Borings were made along the general line of the survey and covered the entire width of any probable location of the channel. The cross sections on which they were taken were generally spaced about 1,500 feet apart, but if the material penetrated was irregular they were put down closer together, and when very regular they were spaced farther apart. They were carried to a depth below the grade of the 30-foot channel, or to bed rock—no attempt being made to penetrate the rock farther than to satisfactorily determine that it was bed rock struck and not detached bowlders. Several diamond-drill borings were put down to determine the character and stratification of the bed rock. They are fully described in the report of R. C. Smith, superintendent of diamond-drill borings, Appendix No. 19. Nearly all of these borings are plotted on the published maps and are designated thus ⊙. The figure preceding this mark indicates the elevation of the bottom of the hole, and, when followed by the letter (R), indicates that rock was struck at that elevation, the object being to determine the elevation of the bed rock, within the limits of any probable excavation, and the character of the material overlying it. Samples were taken of the various kinds of material penetrated, preserved in bottles and properly labeled for identification.

The apparatus used in making the borings is shown in fig. 1. A 2-inch rope passed from the drum over a sheave at the top of the derrick and was attached to the swivel in the top of the 1¼-inch drill rods, which worked inside of 2½-inch flush-joint casing. Both the casing and the rods are those used in ordinary diamond-drill work. With a hand pump water was forced through the hollow drill rods and passed out through four small holes in the cross bit attached to the lower end, and then up to the surface of the ground, through the annular space between the rods and casing, bringing with it all loosened material. The material was loosened, depending on its character, by churning the rods or by turning them with pipe tongs. The casing was worked down by turning with pipe tongs. Bowlders were broken up with dynamite when encountered. It was necessary to haul water in tanks with teams for nearly all the holes, which added materially to the cost of the work.

The force for making borings consisted of 1 superintendent of borings and 3 boring crews, each composed of 1 foreman, 3 laborers, and 1 teamster, with team to haul water and move the machines from hole to hole.

The surveys were begun September 13, 1897, and completed about March 1, 1898, covering a period of five and one-half months. Owing to delays in getting the apparatus for making borings, this part of the work was not begun until November 1, 1897, and completed April 16, 1898, covering a period of five and one-half months.

Using the base line for the standard, and as correct, the average error of closure in horizontal distance for stadia circuits was 1 in 1,250, and the average error of closure in elevation was 0.177 foot.

The survey, including the location of all borings, was plotted on the standard size sheets, 28 inches by 40.5 inches, to a scale of 1: 5000, except in the vicinity of the gulf on the Tonawanda-Olcott route, where a scale of 1: 2500 was used for three sheets. These maps were entirely completed by this party for the survey at Buffalo, for the Lasalle-Lewiston route, and about one-third of the Tonawanda-Olcott route, the other two-thirds of this route being mapped in the main office at Detroit.

The total length of line surveyed was 39 miles, as measured along the center line of the located canal, being divided as follows:

| | Miles. |
|---|---|
| Buffalo, regulating works to foot of Squaw Island | 2.7 |
| Tonawanda-Olcott route, including harber at Olcott | 25.7 |
| Lasalle-Lewiston route | 10.6 |
| Total | 39.0 |

The total cost of borings, which includes plant, repairs, labor, and all other expenses connected therewith, except surveys for location of holes, was $6,582.65, or $168.78 per mile. Four hundred and four borings were put down on the two lines, with a total of 9,624 linear feet, making a cost of $0.684 per linear foot. The plant for both borings and surveys was considered sunk when the work was completed, and its entire cost proportioned against the routes on which it was used. The salary of the assistant engineer was charged to surveys, and no part of it to borings, the object being to have the borings represent actual cost for such work, leaving out the cost of general supervision and the survey for locating them.

The cost of surveys, which includes instruments, tools, labor, and all other expenses connected with the field survey, mapping, and final plans and estimates, was $17,049.30, or $437.16 per mile, making a total cost of the borings, surveys, and estimates $605.94 per mile. This cost includes making the final maps as published, but does not include plotting that part of the Tonawanda-Olcott route done in the Detroit office.

It should be stated that this work was begun with a party energetic though inexperienced in this class of work, and that most of the field work was done during the winter when the weather and the short days were against rapid progress.

## LASALLE-LEWISTON ROUTE.

### LOCATION AND CHARACTER OF MATERIAL TO BE EXCAVATED.

After the contour maps were completed the location of the canal was laid down upon them by the Board, it being the same for the 21 and 30 foot channels. For the estimate for regulated lake surface it was assumed that the works for regulating the level of Lake Erie would be built at the foot of the lake, as shown on plates 84 and 14, and discussed in the special report of the Board on the Regulation of the Level of Lake Erie, Appendix No. 6.

The channel 600 feet wide originates at deep water in the lake and passes to the right of the regulating works through the Erie Basin to the head of Black Rock Harbor, where it narrows up to the regular canal prism and continues to the foot of Squaw Island, where it widens to 600 feet. At the head of the island lock No. 1, with a lift at low water of 8 feet, is located. From the foot of the island the 600-foot channel continues down the Niagara River, passing to the right of Strawberry Island and Grand Island to Tonawanda (at which point the Tonawanda-Olcott route leaves the Niagara River), and thence to the head of Cayuga Island, where the channel contracts to the regular canal prism on leaving the river, and continues in a northwesterly direction through the village of Lasalle and to above the escarpment at Lewiston. It then descends, by a double flight of six locks and a double flight of two locks, to the Niagara River.

There is a level 1,730 feet long between the two flights of locks. The total lift of the two flights at Lewiston at low water is 318.8 feet. From Lewiston to Lake Ontario the river is from 40 to 60 feet deep, and does not require any improvement for a channel of either 21 or 30 feet depth. In the lake, off the mouth of the river, there is a shoal over which vessels drawing 21 feet can pass, but to make a channel 30 feet deep and 1,000 feet wide would require the excavation of about 654,000 cubic yards of sand and gravel.

### MATERIAL.

The material to be excavated on this route is earth, sand, gravel, clay, hardpan, limestone, and shale, but the classification for the purposes of making estimates will consist of solid rock, which includes both the limestone and shale; hardpan and earth, which includes silt, loam, clay, sand, gravel, and all other material which can be easily excavated with steam shovels.

Extending from shore to shore and from lock No. 1 to deep water in Lake Erie there is a ridge of hard limestone, known as corniferous limestone, almost entirely bare except in Black Rock Harbor, where it is covered with sand, gravel, and clay. The rock disappears below grade just below lock No. 1 and shows up again opposite Strawberry

Island, for a distance of about 1 mile, and again opposite Frog Island, for a distance of 500 feet. At this point it disappears below grade again, and then shows up opposite Tonawanda Island. From Tonawanda to the Niagara River at Lewiston the rock is to be found at or above the grade of the channel. The corniferous limestone runs out soon after leaving Lake Erie. From this point the rock outcrop is composed of Salina shales to the vicinity of Lasalle, and the Niagara limestone is found from there to the escarpment.

To determine the character of the rock, five diamond-drill borings were put down at various points north of Lasalle. Boring No. 1 was about one-half mile north of Lasalle and 400 feet to the right of station 910. Light-gray Niagara limestone was struck at elevation 550 feet above sea level and the boring penetrated it 26 feet to elevation 524. It is a hard rock in thin broken strata, but near the bottom a stratum 28 inches thick was struck. The grade of the channel from Lasalle to lock No. 2 is 533.5 feet.

Boring No. 2 is located near Gill Creek and about 740 feet to the right of station 1090. Rock was struck at elevation 579 and penetrated 56 feet to elevation 523. It was limestone in thin broken layers and very dark in color for 34 feet, but the other 22 feet was lighter in color and quite solid.

Boring No. 3 is just above the escarpment and 700 feet to the right of station 1220 of the channel. It is also east of lock No. 2, and just south of Lewiston. The stratification was:

595 to 557. Hard light gray Niagara limestone, quite solid and gradually merging into shale at the bottom.

557 to 491. Niagara shale, firm but easily broken into short pieces. The last 20 feet contains many fossil shells. At the bottom it merges gradually into Clinton limestone.

491 to 460. Hard Clinton limestone of blue-gray color.

460 to 417. Sandstone intermixed with thin layers of red shale. It varies in color from gray, mottled, and red, and is known as Medina sandstone.

Boring No. 4 is located on the side of the escarpment, and is intended as a continuation of boring No. 3. It is about 1,200 feet to the right of station 1240, and opposite lock No. 5. The stratification was:

389 to 367. Very hard light gray sandstone, known as quartzose sandstone.

367 to 330. Firm, red shale mixed with bands of green shale. The line of demarcation between the sandstone and red shale is well defined.

Boring No. 5 is north of Lewiston, and about 2,800 feet to the right of station 1300, where the channel enters the Niagara River. The stratification is:

335 to 239. Soft, red shale, mixed with bands of green shale broken up. Below elevation 264 there are occasional bands of hard shale.

239 to 209. Firm, red shale in thin horizontal layers.

All the rock penetrated by the above five borings is in flat layers, with a dip to the south of about 36 feet to the mile. Practically all the rock to be excavated between Tonawanda and lock No. 2 at Lewiston is limestone, but the excavation for the two flights of locks will include all the different rocks found in borings Nos. 3, 4, and 5. The general character of these rocks is pretty well known and need not be further described or considered except to determine the form of the side slopes in the deep cut at the escarpment, and to decide as to their suitableness for foundations.

As to the latter point, it may be said that all of the rocks will afford good foundations for locks at the elevation required. The limestones and sandstones are solid and firm and show little or no signs of disintegration when exposed to the action of the elements for centuries, but all of the shales when so exposed disintegrate to a greater or less extent. According to geologists the gorge of the Niagara River at Lewiston has been in existence from sixty to one hundred centuries and it has not widened to any great extent during that time, although the exposed faces of the shales show marked signs of disintegration. Nearly vertical faces of Niagara shale are exposed at "The Gulf," west of Lockport and near diamond drill borings No. 3, which show decided indications of disintegration under the action of the elements, but it has stood for centuries without receding more than a few feet. The Erie Canal at Lockport is cut through a ridge of Niagara shale, and the northwest bank of this cut stands nearly vertical and shows but little signs of disintegration, though it has been exposed to the elements over fifty years. During the winters of 1896–97 and 1897–98 the Erie Canal was deepened above Lockport, much of the excavated material being Niagara shale, which, after being broken up and exposed to the action of the weather in the spoil banks, disintegrated very rapidly. This same shale was solid and firm where it formed the walls of the canal prism below the ordinary water level. The shale excavated from the wheel pits at Niagara Falls disintegrated very rapidly when exposed to the action of the weather.

The conclusion reached, after examining the shales found above the escarpment on both routes, is that they are perfectly stable when under water and disintegrate slowly when left in the natural bed, with faces at right angles to it, exposed to the action of the elements, but when broken up and placed in spoil banks they rapidly deteriorate.

The shale found below the escarpment at Lewiston is of a red color and soft near the top, but becomes much harder near the bottom of the proposed excavation. It crumbles rapidly when broken up and exposed to the elements and finally becomes a red clay. It does not disintegrate under water and affords good foundations.

Taking up the material overlying the bed rock and within the limits of the excavation for a channel of 30 feet depth, it is found to be silt, sand, gravel, bowlders, and clay, and may be classified under the one

general head of drift. At Squaw Island it is generally sand and gravel, with a few feet of silt on top, and near the head of the island is found to be gravel and bowlders cemented together, forming a hard mass.

From Squaw Island to the head of Cayuga Island, where the channel leaves the river, sand and gravel are found, which can easily be dredged. From this point to the escarpment a firm yellow clay is found on top, a soft, reddish clay almost entirely free from grit and varying in thickness from 2 to 10 feet is found under this from the river to about 1 mile north of Lasalle. Under this soft clay and extending north to Lewiston is found a mixture of red clay and gravel, which in some places is a perfect hardpan and in other places it is not much harder than a good firm clay. Below the escarpment the drift is sand, gravel, clay, and bowlders—the bowlders being generally limestone, angular in shape, and are probably fragments broken off from the cliff above. As a rule a layer of sand or gravel from 6 to 12 inches thick is found immediately above the rock and below the hardpan or clay from Lasalle to Lewiston.

GRADES.

In connection with the discharge measurements of the Niagara River at Buffalo, which were taken from October, 1897, to December, 1897, by E. E. Haskell, United States assistant engineer, several gauges where established from Lake Erie to the foot of Squaw Island and read to measure the slope of the river at the several points. To determine the slopes farther down the river, I established gauges at Germania Park dock opposite Strawberry Island, Rattlesnake Island, the bridge across the river to Tonawanda Island, near the head of Cayuga Island, and Schlosser's dock, and had them read several times daily from October 23 to December 16. At times of high or low water, caused by strong winds on Lake Erie, each one of these gauges was read every ten minutes during the day. In this way the low water slope of the river under present conditions was determined from point to point. This slope is shown for a low stage on plate 90.

For an elevation of the lake 571.3, the corresponding elevation of the surface of the water in the river at the various points given would be as follows:

| | |
|---|---|
| Foot of Squaw Island | 566.4 |
| Germania Park | 566 |
| Rattlesnake Island | 565.5 |
| Head of Tonawanda Island | 565.13 |
| Head of Cayuga Island | 563.63 |
| Schlosser's Dock | 563.08 |

If the lake be taken as 570.5, then the head of Tonawanda Island would be 564.6 and the head of Cayuga Island 563.17.

For the purposes of making the estimates, the elevation at Tonawanda was taken as 565 and at Cayuga Island as 563.5, which, under present conditions, corresponds with elevation 571 of Lake Erie. But

it is certain that the slope, especially from Tonawanda to Lasalle, will be reduced when the channel 600 feet wide and 30 feet deep is constructed. How much this reduction will be cannot be predetermined on present data, but the water level at Cayuga Island can be regulated within the limits required by depositing the necessary amount of the excavated rock in the river below the head of the island, thereby reducing the cross section of the river to the required area and shape. The elevations of the water surface from deep water in the lake to the head of lock No. 1, on which estimates are based, are for the regulated level 574.5 and for standard low water 571.4. The lock will have a lift at low water, after regulating works are built, of 8 feet, making the grade immediately below 566.5, which corresponds to elevation 571 of the unregulated lake.

The slope is considered as uniform from this point to Tonawanda and to Cayuga Island. From Cayuga Island to lock No. 2 the water surface is 563.5 and level throughout; from Tonawanda to lock No. 2 on the Tonawanda-Olcott route the water surface is 565 and level throughout. The levels below locks No. 2 on each route depend on the lift of the locks, which will be further considered under the head of locks. For the 21-foot channel and 30-foot channel the elevation of the bottom of the channel is 21 feet and 30 feet, respectively, below the low-water surface, following the slope in the river and being level through the canal sections.

Retaining walls and slope walls are provided in accordance with the standard plans and designs, except for the retaining wall between the canal and river from the regulating works to lock No. 1, where it is made of concrete masonry, with a top width of 12 feet and the base not less than two-thirds the height.

The locks are of the standard design adopted by the Board, with such variations as are necessary to fit local conditions at each place.

Their size for the 30-foot channel is 740 feet by 80 feet for single locks, but for double locks one is 60 feet wide and the other 80 feet wide, both being 740 feet long. For the 21-foot channel all locks are 600 feet by 60 feet. The filling and emptying culverts are located in the lock walls. Miter gates are used in all cases. The details of the lock construction are given in Appendix No. 1.

Lock No. 1, at Buffalo, is a double lock of 8 feet lift and founded on solid rock. Its various parts conform to the standard design, except that the wall on the river side is made thicker than the one on the land side on account of having water on both sides of the wall. Water power for driving the operating machinery can be developed above the lock.

Above lock No. 2, at Lewiston, the elevation of low water is 563.5, as heretofore explained. Below lock No. 9 the standard low water of the Niagara River is 244.7, making a total fall of 318.8 feet to be overcome by locks.

From a casual inspection of the profile at this point it is evident that single locks with a basin between would involve an unnecessary amount of excavation. It is also evident that a single flight of locks would seriously delay the traffic when ships were going in opposite directions. To provide the greatest capacity at the minimum cost a double flight of locks should be constructed.

The arrangement finally decided upon is shown on plate 15, and the design is shown on plate 69.

For the 30-foot channel estimates are made on a flight of 6 double locks of 40 feet lift each and a flight of 2 double locks with a lift of 39.4 feet each; also for a flight of 8 double locks of 29 feet each and a flight of 3 double locks with lifts of 28.93 feet each. These estimates show that the locks of 40 feet lift can be built $4,600,000 cheaper than those of 30 feet lift. In both cases there is a level, with connecting side basin, to reduce the fluctuations of the water surface when putting in or taking out a lockful of water between the two flights of locks.

The channel throughout the length of this level and also for 2,500 feet above the head of lock No. 2 is excavated 2 feet below grade, so as to insure a full depth of channel when the locks are being filled.

For the 21-foot channel estimates were made only for locks of 40 feet lift, as it is quite evident that those of 30 feet lift would cost more and would not be so efficient.

Water power for driving the operating machinery and pumping out the locks may be developed cheaply by making an open cut from the channel at a point above lock No. 2 to the top of the bluff near the Suspension Bridge, and then carrying the water down the side of the bluff to the wheel pit situated between the foot of the bluff and the Niagara River.

The tail race can be made by tunneling from the bottom of the wheel pit to the river. This arrangement would give a head of 300 feet. It can also be developed by carrying the water in pipes along the west wall of the locks from the head of lock No. 2 to opposite lock No. 7, where a wheel pit could be made and the tail water pass out through the tunnel to the river. By this arrangement a head of 270 feet can be obtained. The power may then be distributed by electricity or by compressed air to the points required for the two flights of locks.

The power will be needed for lighting, operating the gates and valves, and pumping out lock No. 9. It is evident that locks Nos. 2, 3, 4, 5, and 6 can each be drained into the next lower lock, and a tunnel from the bottom of lock No. 7 to the river will drain this lock and also provide the tailrace for the water used in developing the power. To provide against unequal leakage in the several locks of the flight a pipe 3½ feet in diameter is carried in the middle wall from the head to the foot of the flight. Valves are provided to supply water to

each lock of the flight. The level basin between the two flights is provided with a spillway to carry off surplus water which is not needed in locking through the second flight. It is evident that lock No. 8 can be drained into lock No. 9, but on account of the river being higher than the bottom of the lock, it will be necessary to provide a pumping plant to empty lock No. 9.

The Niagara River from Lewiston to its mouth affords a magnificent harbor 7 miles long and from 40 to 60 feet deep, which already exists and will cost nothing to maintain.

STREAMS CROSSED.

The channel crosses Cayuga Creek, Gill Creek, and Fish Creek, each of which can be taken into the canal.

There is very little or no flow in Cayuga Creek at low stages. Its depth is from 6 to 8 feet and is due to the backwater from Niagara River. The present water surface is therefore about the same as the proposed water surface in the canal. Starting at a point 700 feet to the right of station 885, the prism of the creek can be enlarged and made to enter the canal at station 885 with a width of 300 feet and 10 feet deep, which would give a low-water cross section of 3,000 square feet and bring the flood waters into the channel at a velocity of about one-half foot per second. This would not erode the banks nor interfere with navigation. It is also proposed to put a sill across the creek 3 feet above its bed, so that any sand and silt washed down by the stream would be deposited before entering the canal.

Gill Creek at station 1092 is a small stream, with no flow except at times of rains or melting snows. Its bed is composed of earth and is about 24 feet above the water surface of the canal, but solid rock is found about 5 feet above this water surface. It is proposed to excavate the earth 100 feet wide back about 200 feet and then build a dam or retaining wall up to the bed of the stream. The waters will pour over this wall onto the rock below and then into the channel.

Fish Creek is crossed at station 1214. It has no flow except at times of rain or melting snow, and the flood discharge is small. It is proposed to divert it so that it will enter the canal opposite station 1210. This diversion will be in solid rock, with a channel 100 feet wide and 5 feet below the water surface in the canal for a distance of 50 feet back from the channel line. Back of this point the grade of the diversion will be such as to carry the water from the present bed of the creek.

Bridges and road changes required are as follows:

At station 127 the channel crosses the Grand Trunk Railroad, which will require a single-track swing bridge.

At Lasalle, from station 860 to station 875, it will be necessary to build a combined swing bridge to accommodate the highway travel, and a double track for the Buffalo and Niagara Falls Electric

Railway and 0.5 mile of new road; a double-track swing bridge for the New York Central Railroad and 1.8 miles of new roadbed, and a single-track bridge for the Erie Railroad and 2.1 miles of road.

It is also necessary to build 1.5 miles of new highway to the right of the channel. The highway travel can be accommodated by a ferry at station 910.

At station 1040 a double-track swing bridge should be built for the New York Central Railroad, and also to accommodate the highway travel. It will also be necessary to move the junction of the Niagara Construction Company's Railroad farther west, involving the building of 1.3 miles of new roadbed.

A highway bridge must be provided near station 1188.

At Lewiston a crossing must be provided for the New York Central and the Rome, Watertown and Ogdensburg railroads, which may be done by building a fixed bridge across the channel at Lock No. 4, near station 1235, and bringing both roads to it on top of the bluff, instead of following down the gorge of the Niagara River, as at present. After crossing the bridge both roads would drop to the level of the lower plane by an easy descent along the side of the escarpment and to the present junction of the two roads. Lewiston could then be reached by a separate line to the east of Lock No. 9.

This would require the building of 5.9 miles of new double-track and 3 miles of single-track road.

A highway crossing in the village of Lewiston must be provided which can also be used for the crossing of the electric railway. This can be accomplished by building a bridge over Lock No. 9 and connecting the railways with it on both sides, involving the building of 1.3 miles of single-track electric railway.

A tunnel under the canal must also be provided at Buffalo for carrying the water supply from the in-take pipes to the waterworks pumps.

Estimates are based on the following widths of channel:

From deep water in Lake Erie to Black Rock Harbor, 600 feet wide; from Black Rock Harbor to the foot of Squaw Island, canal section, in the Niagara River, 600 feet wide; from Lasalle to the river at Lewiston, standard canal section.

Table No. 1, following, shows the existing railways and highways that cross the proposed center line; No. 2, the location, length, and cost of the proposed bridges required on this route; No. 3, the location, cost, etc., of locks; No. 4, the detailed estimates for 30-foot channel, and No. 5 the detailed estimates for the 21-foot channel.

TABLE NO. 1.—*Existing crossings—Lasalle-Lewiston route.*

| Location. | | Present grade. | Remarks. |
|---|---|---|---|
| Place. | Station. | | |
| *Railway.* | | | |
| International bridge | 128 | 590.0 | Single-track railroad between bridge over Niagara River and the one over Black Rock Harbor. |
| Lasalle | 852+50 | 573.0 | Buffalo and Niagara Falls Electric R. R., double track. |
| Do | 853+50 | 576.0 | New York Central and Hudson River R. R., double track, Buffalo and Niagara Falls branch. |
| Do | 854+50 | 576.0 | New York, Lake Erie and Western R. R., single track, Buffalo and Niagara Falls branch. |
| | 1040 | 604.0 | New York Central and Hudson River R. R., double track, Niagara Falls and Lockport branch. |
| Lewiston | 1236 | 548.0 | Rome, Watertown and Ogdensburg R. R., single track. |
| Do | 1245 | 370.0 | New York Central and Hudson River R. R., Niagara Falls and Lewiston branch, single track. |
| Do | 1258 | 345.0 | Do. |
| *Highways.* | | | |
| Lasalle | 852+50 | 573.0 | River road. |
| | 860 | 574.0 | |
| | 864 | 574.0 | Not much used. |
| | 909 | 573.0 | Mile-line road. |
| | 991 | 597.0 | Packard road. |
| | 1019, 1023, 1027 | ..... | Streets laid out, but in no way improved. |
| | 1031, 1034, 1035 | ..... | |
| | 1048 | 606.0 | Lockport road. |
| | 1052, 1057 | ..... | Streets plotted, but not improved. |
| | 1061, 1065 | ..... | |
| | 1095 | 603.0 | Witmere road. |
| | 1188 | 616.0 | Reservation road. |
| | 1225 | 593.0 | River road. |
| Lewiston | 1277 | 346.0 | Center street, single-track electric railroad, Lewiston to Youngston. |
| Do | 1284 | 360.0 | Second street or River road; streets are also crossed at 1258, 1264, 1271, and 1290, but they are only slightly improved. |

TABLE NO. 2.—*Location, cost, etc., of proposed bridges—Lasalle-Lewiston Route.*

| Location. | Station. | Kind of bridge. | Number of tracks. | Swing or fixed. | Number of spans. | Thirty-foot channel. | | Twenty-one foot channel. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Total length. | Estimated cost. | Total length. | Estimated cost. |
| International bridge. | 128 | Railway | 1 | Swing | 1 | 537½ | $146,686 | 517½ | $129,650 |
| Lasalle | 861 | Highway and electric railway. | 2 | do | 1 | 550 | 155,230 | 530 | 130,206 |
| Do | 868 | Railway | 2 | do | 1 | 550 | 225,607 | 530 | 204,575 |
| Do | 874 | do | 1 | do | 1 | 537½ | 128,230 | 517½ | 155,398 |
| Do | 1040 | Highway and railway. | 2 | do | 3 | 711 | 303,628 | 687 | a 276,033 |
| Do | 1188 | Highway | | do | 1 | 580 | 68,546 | 556 | 63,478 |
| Do | 1235 | Railway | 2 | Fixed | 1 | 353 | 101,572 | 333 | 92,366 |
| Lewiston | 1292 | Highway and electric railway. | 1 | Swing | 1 | 240½ | 47,434 | 197 | 44,098 |
| Do | | Bridges not over canal. | | | | | | | |
| Lasalle | 890 | Highway | | Fixed | 1 | 100 | 8,504 | 100 | 8,504 |
| Do | 1235 | Railway | 2 | do | 1 | 30 | 7,095 | 30 | 7,095 |
| Total | | | | | | | 1,192,382 | | 1,109,403 |

a Double-deck, draw span, and two 63-foot girders.

NOTE.—

| | Feet clear opening. |
|---|---|
| Highway bridges | 22 |
| Single-track railway bridges | 14 |
| Double-track railway bridges | 26 |
| Double-track double-deck bridges | 29 |

TABLE No. 3.—*Lasalle-Lewiston route.*

LOCKS.

| Location. | | Length of level above. | No. | Lift. | Kind. | | Elevation standard, low water. | |
|---|---|---|---|---|---|---|---|---|
| Place. | Station. | | | | Single or double. | Individual or in flight. | Above lock. | Below lock. |
| | | *Miles.* | | *Feet.* | | | | |
| Buffalo | 88+97 | | 1 | 8 | Double | Individual | 574.5 | 566.5 |
| Lewiston, upper flight | 1220+47 | 21.3 | 2 | 40 | do | Flight | 563.5 | 523.5 |
| Do | | | 3 | 40 | do | do | 523.5 | 483.5 |
| Do | | | 4 | 40 | do | do | 483.5 | 443.5 |
| Do | | | 5 | 40 | do | do | 443.5 | 403.5 |
| Do | | | 6 | 40 | do | do | 403.5 | 363.5 |
| Do | 1257+47 | | 7 | 40 | do | do | 363.5 | 323.5 |
| Lewiston, lower flight | 1284+47 | 0.4 | 8 | 39.4 | do | do | 323.5 | 284.1 |
| Do | 1291+87 | | 9 | 39.4 | do | do | 284.1 | 244.7 |

COST.[a]

| Location. | 30-foot channel. | 21-foot channel. | Operating machinery. |
|---|---|---|---|
| Buffalo | [b]$1,720,358 | [b]$1,135,413 | $100,000 |
| Lewiston, upper flight | 12,296,609 | 8,206,614 | 500,000 |
| Lewiston, lower flight | 4,420,037 | 2,952,169 | |
| Total | 18,437,004 | 12,294,196 | 600,000 |
| Operating machinery | 600,000 | 600,000 | |
| Total | 19,037,004 | 12,894,196 | |

[a] The cost is that of the structure complete except the excavation.
[b] For regulated lake level.

TABLE No. 4.—*Estimate for 30-foot channel.*

NIAGARA RIVER (FROM STATION —85 TO STATION 829).

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *With regulating works.* | | | |
| Earth, cubic yards | 13,009,221 | $0.15 | $1,951,383 |
| Rock, dry, do | 90,014 | 1.00 | 90,014 |
| Rock, wet (in Lake Erie), do | 1,687,650 | 3.00 | 5,062,950 |
| Rock, wet (in Niagara River), do | 9,128,800 | 2.00 | 18,257,600 |
| Hardpan, do | 4,200 | .30 | 1,260 |
| Regulating works | | | 796,923 |
| Lock No. 1 | | | 1,720,358 |
| Operating machinery | | | 100,000 |
| Total | | | 27,980,488 |
| *Without regulating works.* | | | |
| Earth, cubic yards | 13,045,421 | .15 | 1,956,813 |
| Hardpan, do | 4,200 | .30 | 1,260 |
| Rock, dry, do | 90,014 | 1.00 | 90,014 |
| Rock, wet (in Lake Erie), do | 2,227,900 | 3.00 | 6,683,700 |
| Rock, wet (in Niagara River), do | 9,424,300 | 2.00 | 18,848,600 |
| Lock No. 1 | | | 1,726,838 |
| Operating machinery | | | 100,000 |
| Total | | | 29,407,225 |
| *Quantities common to both plans.* | | | |
| Retaining wall, cubic yards | 224,148 | 4.00 | 896,592 |
| Slope wall, square yards | 22,957 | 1.10 | 25,253 |
| Back fill, cubic yards | 223,702 | .25 | 55,926 |
| Timber cribs, pine, feet B. M. | 756,860 | [a]30.00 | 22,706 |
| Hemlock, do | 4,012,480 | [a]23.00 | 92,287 |
| Oak, do | 48,000 | [a]50.00 | 2,400 |
| Iron, pounds | 436,330 | .03 | 13,090 |
| Stone fill, cubic yards | 58,860 | .60 | 35,316 |
| Bridges, number | 1 | | 146,686 |
| Right of way, acres | 46 | 4,000.00 | 184,000 |
| Tunnel waterworks, linear feet | 1,000 | 30.00 | 30,000 |
| Total | | | 1,504,256 |

[a] Per 1,000 feet.

TABLE NO. 4.—*Estimate for 30-foot channel*—Continued.

SUMMARY FOR NIAGARA RIVER.

| | |
|---|---|
| With regulating works: | |
| Excavation, etc | $27,980,488 |
| Retaining wall, etc | 1,504,256 |
| Total | 29,484,744 |
| Without regulating works: | |
| Excavation, etc | 29,407,225 |
| Retaining walls, etc | 1,504,256 |
| Total | 30,911,481 |

CANAL SECTION (STATION 829 TO STATION 1313).

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *Excavation.* | | | |
| Lasalle to foot of the first flight of locks (829 to 1262+21): | | | |
| Earth ..... cubic yards.. | 6,707,150 | $0.20 | $1,341,430 |
| Hardpan ..... do.... | 1,094,400 | .30 | 328,320 |
| Rock ..... do.... | 20,091,400 | .65 | 13,059,410 |
| Foot of first to foot of second flight of locks (1262+21 to 1296+61): | | | |
| Earth ..... cubic yards.. | 2,030,477 | .20 | 406,095 |
| Rock ..... do.... | 1,997,486 | .65 | 1,298,353 |
| Foot of second flight of locks to 30-foot depth, Niagara River (1296+61 to 1313): | | | |
| Earth ..... cubic yards.. | 170,378 | .20 | 34,076 |
| Rock, dry ..... do.... | 112,496 | .65 | 73,122 |
| Rock, wet ..... do.... | 190,296 | 1.75 | 333,018 |
| *Walls, locks, etc.* | | | |
| Retaining wall ..... cubic yards.. | 105,881 | 4.00 | 423,524 |
| Slope wall ..... square yards.. | 29,713 | 1.10 | 32,684 |
| Back fill ..... cubic yards.. | 827,794 | .25 | 206,949 |
| Timber cribs: | | | |
| Pine ..... feet B. M.. | 170,960 | *a* 30.00 | 5,129 |
| Hemlock ..... do.... | 1,138,080 | *a* 23.00 | 26,176 |
| Oak ..... do .... | 7,440 | *a* 50.00 | 372 |
| Iron ..... pounds.. | 119,435 | .03 | 3,583 |
| Stone filling ..... cubic yards.. | 15,900 | .60 | 9,540 |
| Locks 2 to 9, inclusive ..... | | | 16,716,646 |
| Operating machinery ..... | | | 500,000 |
| Bridges ..... number.. | 9 | | 1,045,846 |
| Steam ferries ..... do.... | 1 | | 20,000 |
| Railroad changes ..... | | | 363,424 |
| Entrances of streams ..... | | | 20,255 |
| Right of way: | | | |
| Village property ..... acres.. | 856 | | 728,800 |
| Farm property ..... do.... | 2,055 | | 272,250 |
| Total ..... | | | 37,249,002 |

*a* Per 1,000 feet.

MOUTH OF NIAGARA RIVER (STATION 1655 TO STATION 1703).

| | | | |
|---|---|---|---|
| *Excavation.* | | | |
| Earth ..... cubic yards.. | 654,075 | $0.15 | $98,111 |

SUMMARY.

| | With regulating works. | Without regulating works. |
|---|---|---|
| Niagara River ..... | $29,484,744 | $30,911,481 |
| Canal section ..... | 37,249,002 | 37,249,002 |
| Mouth of river ..... | 98,111 | 98,111 |
| Total ..... | 66,831,857 | 68,258,594 |

TABLE NO. 5.—*Estimate for 21-foot channel.*

NIAGARA RIVER (FROM STATION 38 TO STATION 829).

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *With regulating works.* | | | |
| Earth ..... cubic yards.. | 6,809,904 | $0.15 | $1,021,486 |
| Rock, dry ..... do.... | 13,219 | 1.00 | 13,219 |
| Rock, wet (in Lake Erie) ..... do.... | 419,850 | 3.00 | 1,259,550 |
| Rock, wet (in Niagara River) ..... do.... | 2,561,800 | 2.00 | 5,123,600 |
| Regulating works ..... | ..... | ..... | 796,923 |
| Lock No. 1 ..... | ..... | ..... | 1,135,413 |
| Operating machinery ..... | ..... | ..... | 100,000 |
| Total ..... | ..... | ..... | 9,450,191 |
| *Without regulating works.* | | | |
| Earth ..... cubic yards.. | 6,846,154 | .15 | 1,026,923 |
| Rock, dry ..... do.... | 13,219 | 1.00 | 13,219 |
| Rock, wet (in Lake Erie) ..... do.... | 718,100 | 3.00 | 2,154,300 |
| Rock, wet (in Niagara River) ..... do.... | 2,843,950 | 2.00 | 5,687,900 |
| Lock No. 1 ..... | ..... | ..... | 1,141,893 |
| Operating machinery ..... | ..... | ..... | 100,000 |
| Total ..... | ..... | ..... | 10,124,235 |
| *Quantities common to both plans.* | | | |
| Retaining wall ..... cubic yards.. | 224,148 | 4.00 | 896,592 |
| Slope wall ..... square yards | 23,887 | 1.10 | 26,276 |
| Back fill ..... cubic yards.. | 213,830 | .25 | 53,458 |
| Timber cribs, pine ..... feet B. M.. | 756,860 | *a* 30.00 | 22,706 |
| Hemlock ..... do .... | 2,693,240 | *a* 23.00 | 61,945 |
| Oak ..... do.... | 48,000 | *a* 50.00 | 2,400 |
| Iron ..... pounds.. | 311,340 | .03 | 9,340 |
| Stone fill ..... cubic yards.. | 41,010 | .60 | 24,606 |
| Bridge ..... number.. | 1 | ..... | 129,650 |
| Right of way ..... acres.. | 46 | ..... | 184,000 |
| Tunnel waterworks ..... linear feet.. | 1,000 | 30.00 | 30,000 |
| Total ..... | ..... | ..... | 1,440,973 |

*a* Per 1,000 feet.

SUMMARY FOR NIAGARA RIVER.

| | |
|---|---|
| With regulating works: | |
| Excavation, etc ..... | $9,450,191 |
| Retaining walls, etc ..... | 1,440,973 |
| Total ..... | 10,891,164 |
| Without regulating works: | |
| Excavation, etc ..... | 10,124,235 |
| Retaining walls, etc ..... | 1,440,973 |
| Total ..... | 11,565,208 |

CANAL SECTION (STATION 829 TO STATION 1310).

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *Excavation.* | | | |
| Lasalle to foot of the first flight of locks (829 to 1255 + 01): | | | |
| Earth ..... cubic yards.. | 5,670,161 | $0.20 | $1,134,032 |
| Hardpan ..... do.... | 824,650 | .30 | 247,395 |
| Rock ..... do.... | 16,089,387 | .65 | 10,458,102 |
| Foot of first to foot of second flight of locks (1255 + 01 to 1296 + 61): | | | |
| Earth ..... cubic yards.. | 1,934,954 | .20 | 386,991 |
| Rock ..... do.... | 1,181,361 | .65 | 767,885 |
| Foot of second flight of locks to water 21 feet deep, in lower river (1296 + 61 to 1310): | | | |
| Earth ..... cubic yards.. | 103,478 | .20 | 20,696 |
| Rock, dry ..... do.... | 107,900 | .65 | 70,135 |
| Rock, wet ..... do .... | 64,229 | 1.75 | 112,401 |

TABLE NO. 5.—*Estimate for 21-foot channel*—Continued.

CANAL SECTION (STATION 829 TO STATION 1310)—Continued.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *Walls, locks, etc.* | | | |
| Retaining wall ..... cubic yards.. | 40,624 | $4.00 | $162,496 |
| Slope walls ..... square yards.. | 45,540 | 1.10 | 50,094 |
| Back fill ..... cubic yards.. | 372,275 | .25 | 93,069 |
| Crib walls: | | | |
| Pine ..... feet B. M.. | 470,710 | *a* 30.00 | 14,121 |
| Hemlock ..... do .... | 4,606,915 | *a* 23.00 | 105,959 |
| Oak ..... do .... | 59,724 | *a* 50.00 | 2,986 |
| Iron ..... pounds.. | 431,586 | .03 | 12,948 |
| Stone fill ..... cubic yards.. | 63,306 | .60 | 37,984 |
| Locks 2 to 9, inclusive ..... | ..... | ..... | 11,158,783 |
| Operating machinery ..... | ..... | ..... | 500,000 |
| Bridges ..... number.. | 9 | ..... | 979,753 |
| Steam ferry ..... | 1 | ..... | 20,000 |
| Railroad changes ..... | ..... | ..... | 363,424 |
| Entrances of streams ..... | ..... | ..... | 20,255 |
| Right of way ..... | ..... | ..... | ..... |
| Village property ..... acres.. | 856 | ..... | 728,800 |
| Farm property ..... do .... | 2,055 | ..... | 272,250 |
| Total ..... | ..... | ..... | 27,720,559 |

*a* Per 1,000 feet.

SUMMARY.

| | With regulating works. | Without regulating works. |
|---|---|---|
| Niagara River ..... | $10,891,164 | $11,565,208 |
| Canal section ..... | 27,720,559 | 27,720,559 |
| Mouth of river ..... | 0 | 0 |
| Total ..... | 38,611,723 | 39,285,767 |

## TONAWANDA-OLCOTT ROUTE.

### LOCATION.

As before stated, the location of this route is identical with that of the Lasalle-Lewiston route from Lake Erie to station 541, opposite Tonawanda. At this point it swings to the right, passes just above the head of Tonawanda Island, and leaves the river near the bridge, connecting the mainland with the island, and continues through the city of North Tonawanda and to Olcott, as shown on plates 16 and 17. Another location was considered, leaving the river near the foot of the island, swinging to the right, and joining the adopted location in the vicinity of Sawyers Creek, but this was abandoned for the reason that it gives bad alignment and leaves the river at nearly right angles to the general direction of the current. The latter condition would make it very difficult, if not impossible under some conditions, to manage ships when passing from the river section to the canal section, and vice versa. The location adopted gives an easy curve for leaving the river and a good alignment thereafter. The cost of the two locations is about the same. A different location was also considered from Sawyers Creek to below the escarpment west of Lockport. This would leave the adopted location in the vicinity of Saw-

yers Creek, swing to the right and cross the Erie Railroad about opposite station 900, and continue south of the railroad to about opposite station 1200, where it would swing to the left to the head of the gulf and thence by a tangent to the main line at station 1375. This would require two extra railroad crossings, but the most serious objection is the sharp curve necessary to reach the head of the gulf. The alignment is bad.

A preliminary study was made of a location entering the gorge of Eighteen Mile Creek in the vicinity of the village of Newfane, and continuing down the creek to Olcott, but the difficulties of constructing a channel on this location were such as to make it more expensive than a line entirely independent of the gorge. Estimates in detail were not, therefore, made on this line.

From station 1245 to station 1658 an alternate line is estimated, which is shown on the maps as "B line." The difference in cost of the two lines from station 1245 to station 1658, common points on both, is $398,000 for the 30-foot channel and $543,800 for the 21-foot channel in favor of the "A" or adopted line. The alignment of the adopted line is better and it would be much more satisfactory to navigate.

The material to be excavated is similar to that found on the Lasalle-Lewiston route.

Limestone rock appears above the grade of the 30-foot channel between stations 602 and 607, and then dips below grade and reappears at station 715 and continues above grade to station 775, where it dips below grade and reappears at station 870, and then continues above the grade to station 1345 at the second escarpment. From the foot of lock No. 5 to Lake Ontario the rock is the so-called red shale. It is in flat layers from 1 to 3 inches thick, though at rare intervals layers of 4 to 6 inches are found. For a depth varying in different localities from 10 to 30 feet these layers are separated one from another by a thin layer of reddish mineral dirt, and they are broken into small pieces, which gives it the appearance of being soft shale, but in fact each individual piece is quite hard. On breaking a solid piece at right angles to its bed it is seen that the interior portion is a dark-gray color and the outer portions are of a reddish color. In these respects it differs from the red shale found at Lewiston.

### DIAMOND-DRILL BORINGS.

To determine the character of the rock nine diamond-drill borings were put down on this line. The location of each is shown on plates 16 and 17, and they are described in the report of R. C. Smith, Appendix No. 19.

Boring No. 1 is located at Sawyers Creek, 250 feet to the left of station 766. Rock was struck at elevation 545 and penetrated 16 feet to elevation 529, which is 6 feet below the grade of the channel.

The rock is a very hard light-gray limestone, much broken up and in layers one-quarter inch to 3½ inches thick.

Boring No. 2 is just east of Pendleton Center and 900 feet to the right of station 1010. Limestone rock was struck at elevation 566 and was penetrated 89 feet to elevation 477. The first 50 feet was hard Niagara limestone, in thin layers near the top and thicker layers toward the bottom, one being 22 inches thick. The next 39 feet was a very hard limestone conglomerate of dark color.

Boring No. 3 is near the gulf west of Lockport and 1,400 feet to the right of station 1266. The stratification is:

588 to 582. Soft limestone, full of shells.
582 to 572. Mixture of limestone and sandstone in hard, thin layers.
572 to 502. Firm Niagara shale.
502 to 490. Limestone.
490 to 465. Limestone and shale, with few layers of green shale at the bottom.
465 to 425. Medina sandstone mixed with red and green shale.
425 to 407. Very hard Medina sandstone mixed with hard red shale.
407 to 399. Hard Medina sandstone.
399 to 388. Sand shale mixed with gray sandstone, shale softer.

By comparing this with borings Nos. 3 and 4, at Lewiston, it will be seen that the stratification is nearly the same in both cases and that the different materials were found at about the same elevation.

Borings Nos. 4 and 5 were put down through Niagara limestone to determine, in connection with boring No. 3, the elevation and dip of the shale, but no attempt was made to penetrate the shale. No. 4 is located 250 feet to the right of station 1238. The elevation of shale is 558. No. 5 is 750 feet to left of station 1277. Elevation of shale, 580. These give a dip of 5.6 feet per 1,000 feet, and if the same rate of inclination continues to the south, the shale would dip below the bottom of the channel near station 1200.

Boring No. 6 is located 600 feet to the left of station 1316, at which station the grade of canal is 504 feet for 21-foot channel. Rock is found at the surface.

523 to 501. Clinton limestone. The last 15 feet contains layers of green shale.
501 to 486. Hard green, red, and gray sandstones, mixed with red shale and Clinton shale.
486 to 432. Medina sandstone, gray and red; the last 20 feet pink in color; all very hard.
432 to 400. Gray sandstone and shale mixed.
400 to 393. Firm red and green shales.
393 to 385. Soft red shale.
385 to 332. Firm red shale.

Boring No. 7 is located 1,250 feet to the left of station 1400. The grade of 21-foot channel is 344 at this station. Soft red shale was

struck at elevation 353 and continued to 310; from this elevation to 267 firm red shale was found.

Boring No. 8 is located 600 feet to the left of station 1581. The elevation of grade of 21-foot channel is 344. Soft red shale was struck at elevation 345, changing to firm red shale at 328 and continuing to elevation 176.

Boring No. 9 is located at the shore line of Lake Ontario near Olcott, and 150 feet to the left of station 1893. The grade at station 1893 is 223.5 for 21-foot channel. The stratification is as follows:

251 to 242. Sand and gravel.
242 to 223. Soft red shale.
223 to 206. Firm red shale.
206 to 182. Firm red shale, mixed with soft Medina sandstone.

It will be seen from these borings that all of the rock to be excavated above the second escarpment is either limestone or firm shale and below this point it is either soft or firm red shale. The general characteristics of these several rocks, except the red shale, are the same as those for the Lasalle-Lewiston route and need not be further considered here except to state that the shales south of station 1350 will cost about as much to excavate as the limestone, and from this station to Lake Ontario the top 15 feet will be much easier to excavate.

An examination of the shale found along the Erie Canal near Lockport shows it to be a well-defined shale, much softer and more broken than the limestone, but to the southwest it gradually becomes harder and in general appearance more like the limestone. At the point where it dips below the grade of the Erie Canal it is difficult to distinguish between the two from external appearances.

The material overlying the bed rock is sand and gravel from station 541, in the Niagara River, to station 600. From station 600 to station 1100, near Hodgeville, the top 6 to 15 feet is a firm yellow clay mixed with varying quantities of sand. Below this is found a soft red clay varying in thickness from 5 to 20 feet. From station 600 to station 940 it is generally from 15 to 20 feet, and from station 940 to station 1100 it is from 5 to 10 feet thick. It is a pure clay, almost entirely free from grit. Under this soft clay and overlying the bed rock is a mixture of red clay and gravel varying in hardness from a good hard clay to hard-pan or bowlder clay. From station 1100 to the gorge of Eighteen-Mile Creek it is a drift composed of clay mixed with sand and gravel, and may be classed as a firm clay. In the gorge of Eighteen-Mile Creek to Olcott it is a very soft silt and sand.

### GRADES AND LOCKS.

As already explained, the water surface at the point where the channel leaves the Niagara River is taken at elevation 565 and continues level to lock No. 2. The slope required to carry the necessary water for lockage and power development is very slight. Lock No. 2 has a lift of 40 feet, so that the elevation of the water surface below

it is 525 and continues level to the head of the flight of three double locks, Nos. 3, 4, and 5, which have a lift of 40 feet each, making the elevation of the water surface below the flight 405, which continues level to lock No. 6, with a lift of 40 feet, making the level of the water surface below 365 feet, which continues level to lock No. 7, with a lift of 30½ feet, making the water surface below 334.5, which continues level to the head of the flight of three double locks, Nos. 8, 9, and 10, with a lift of 30 feet each, making the water surface below lock No. 10 244.5, which is the level of low water in Lake Ontario. The grade of the 21 and 30 foot channels is 21 and 30 feet, respectively, below the water surface. The location and lift of locks are the same for both channels.

As before stated, the lock chambers for the 30-foot channel are 740 by 80 feet for single locks, but for double locks one is 740 by 80 feet, and the other 740 by 60 feet.

*Regulation of water surface in pools between locks Nos. 2 and 3 and 5 and 6.*—Locks Nos. 2 to 6, inclusive, all have the same lift. Locks Nos. 2 and 6 are single locks 80 feet wide, while Nos. 3, 4, and 5 constitute a double flight. The flight on the right is 80 feet wide, while that on the left is but 60 feet wide. In the consideration of the locks, it is assumed that vessels will ordinarily use the right-hand flight of locks; that is, down-bound vessels will use the 80-foot locks and up-bound vessels the 60-foot locks. Vessels passing down consecutively will leave no change in the water levels in the two pools between the locks after they have passed out. Vessels locking consecutively upward will lower the level of the lower pool and raise that of the upper pool. Vessels alternating will raise the lower pool and lower the upper one. These contingencies, as well as any deficiency in the long level between locks Nos. 6 and 7, have been provided for by the construction of open channels around lock No. 2 and also the flight, and by making use of the bed of Sherman Creek, at lock No. 6. The channel at lock No. 2 is controlled by sluice gates so that the required amount of water may be supplied the basin below. The channel connecting the upper and lower pools is provided with a small weir and sluice gate. The weir serves to pass any excess of water in the upper pool and the sluice gate to supply deficiencies in the lower pool. The lower pool is enlarged on the left by the construction of an embankment around the low ground, no excavation being required, and is regulated by a small weir discharging into the old bed of Sherman Creek. Sherman Creek crosses the level between locks Nos. 6 and 7 just below lock No. 6 by means of a discharge weir over the right side of the canal. This weir also serves to regulate the water in this level.

## POWER.

Electric power for operating the valves, gates, pumps, etc., can be developed by taking water from the level above lock No. 2 and leading it through a tunnel and pipes to the power house, about 1,200 feet

to the right of station 1290, using the gulf and Eighteen-Mile Creek as a tail race. A head of 100 feet can be obtained. From this central station the power can be distributed to each of the locks on this route, excepting lock No. 1, at Buffalo, where it would be cheaper to develop power near the site of the lock.

"B" LINE.

The "B" line leaves the main line at station 1245, swings to the right, and enters the gulf about station 1281, where a flight of two double locks with a lift of 40 feet each is to be built, making the elevation of the level below 485.

It then follows the gulf to station 1308 and swings to the left to station 1360, where a flight of three double locks with 40 feet lift each is put in, making the level of the water below 365, which is carried to station 1630, where a single lock of 30½ feet lift is put in, making the level below 334.5, the same as below lock No. 7 on the main line.

It then joins the main line at station 1658, and from this point to Lake Ontario the two lines are identical.

A masonry dam 70 feet high across the gulf would be required to the right of station 1327. The west branch of Eighteen-Mile Creek would be taken into the channel at station 1400 and pass out over a spillway at station 1490. Six highway bridges and 2 miles of new highway would be necessary.

Power for operating valves, gates, pumps, etc., can be developed by taking water from the channel about station 1335 and carrying it by canal and pipes to the power house in the gulf, which would be used as a tail race. A net head of 110 feet can be had. However, this would require a by-pass about 1,000 feet long to carry the water to the left of lock No. 2 from the upper level to the gulf opposite station 1290. A net head of 70 feet could also be utilized at this point, making a total net head available of 180 feet if two separate plants are installed. The power thus developed can be distributed electrically to all of the locks on the route except No. 1, at Buffalo.

Estimates are based on the following widths for both the 21 and 30 foot channels:

In Niagara River, 600 feet wide.

From the Niagara River to the gorge of Eighteen-Mile Creek, at the foot of lock No. 10, standard canal sections. Foot of lock No. 10 to Lake Ontario, 400 feet wide. From the shore of the lake to deep water, 600 feet wide.

HARBOR.

The harbor at Olcott is shallow, with a shale rock bottom, which must be excavated to the required depth and a breakwater built to protect it from the waves of the lake. The discussion and estimate of the breakwater are given in Appendix No. 3. The design of the channel from the foot of lock No. 10 to the lake contemplates an

inner harbor 400 feet wide and about a mile long, so that it will not be necessary to make any further excavation in the lake than the 600-foot channel until the volume of traffic requires it.

It will be necessary to make provision for taking care of the flood waters of the streams on this route.

Tonawanda Creek can enter the Niagara River as at present without any additional work.

Sawyers Creek, at station 767, has a flood discharge of about 1,200 cubic feet per second and practically no flow during dry weather. The bed of the stream is at about elevation 570, or 5 feet above the low water in the canal. The bottom of the canal at this point is in solid rock and retaining walls are built on each side. It is proposed to fill the bed of the creek on the right to the level or above the top of the retaining wall; on the left, for a length of 200 feet, the wall will be built to elevation 555, giving a sectional area of opening at low water of 2,000 square feet, through which the water can pass into the canal. This area will be larger at high water. A basin 200 feet wide and 600 feet long will be excavated to elevation 552, in which the sediment will be deposited before entering the canal. At the upper end of this basin a dam will be built to the elevation of the present bed of the stream.

Bull Creek is crossed at station 841, where the bottom of the canal is in earth. It can be taken into the canal through a basin 100 feet wide and 10 feet deep excavated back 500 feet, with a dam for holding back the earth. The bottom and sides of the basin to above the high-water line should be paved near the canal.

The method of taking care of the flood waters of the small creek crossed just below Lock No. 6 has already been described.

The next and last stream is Eighteen-Mile Creek, which has practically no discharge at low water under normal conditions, but under existing conditions its low-water flow depends on the amount of water being drawn from the Erie Canal at Lockport. No measurements could be obtained of its flood discharge. The back water from Lake Ontario extends to the railroad bridge, some 3,000 feet above where the canal enters the creek, and if the dirt overlying the rock is excavated back for a distance of 1,000 feet it will give ample room for sedimentation before the waters enter the canal.

In the event the canal should be built on this route, a number of changes of both railroads and highways will be necessary, and bridges must be built to cross the canal. These changes and structures would be subject to agreement between the United States and the several parties interested, and the final disposition might be materially changed from any project now submitted. This statement applies with equal force to all the routes considered. However, for the purpose of estimating the cost of the work, the following project is suggested.

A rearrangemen of the railroads should be made in the vicinity of Tonawanda. The yards of the New York Central and the Erie railroads should be moved entirely north of the channel, and the alignment of the Lockport branch of the New York Central should be changed to leave the main line about one-half mile north of station 610, and then continue in a straight line to a junction with the present location near Sawyers Creek. The Lockport branch of the Erie Railroad, which has recently been converted into an electric road, should leave the main tracks about 1,000 feet south of station 617 and follow the present line of the New York Central road to opposite station 660, where it would join the existing line of the Erie. This arrangement would locate the Lockport branch of the Erie road entirely to the right and that of the New York Central entirely to the left of the canal.

Taking up the bridges and road changes in regular order, beginning at the Niagara River, we have the following:

1. Move bridge at station 600 about 1,000 feet downstream.
2. Build new highway bridge at station 607.
3. Build new double-track bridge at station 613 for the New York Central Railroad. (Bridges 2 and 3 may be combined into one, but the cost would be about the same in either case.)
4. Build single-track swing bridge at station 619 for Erie Railroad.
5. Build combined highway and single-track electric railway bridge at station 625.
6. Build combined highway and double-track electric railway bridge at station 641.
7. Build highway bridge at station 670.
8. Build highway bridge at Sawyers Creek, station 765, and change Shawnee road to the west of New York Central Railroad so as to reach this bridge.
9. Build highway bridge at station 849 and change both the Bear Ridge and Town Line roads to cross this bridge.
10. Build highway bridge at station 1026 and change the Pendleton, Sulphur Springs, and Hodgeville roads to cross this bridge.
11. Build combined highway and double-track bridge for New York Central Railroad at station 1232, and change both highway and railroad to cross at this point, and build new highway to left of channel from station 1232 to station 1302.
12. Build highway bridge over Lock No. 2, at station 1302, and change Gulf road on east side to connect with it.
13. Build highway bridge at Lock No. 6, station 1394, and change road to cross it.
14. Put in ferry for highway crossing at station 1454.
15. Build highway bridge over Lock No. 7 and change road to cross it.
16. Build highway bridge at station 1700.
17. The canal crosses the Rome, Watertown and Ogdensburg Railroad above the head of Lock No. 8, station 1808. The elevation of the

low water on this level is 334.5 and the high water about 336. If the top of the center pier is made 3 feet above high water and the top of the rail 14 feet above the top of the pier, we would have 336+3+14=353 for the grade of the railroad, if crossing at this point. The elevation of the present grade of the road is about 318. It would, therefore, be necessary to raise the roadbed 35 feet at the canal crossing and extend the filling each way some 4,000 feet, and rebuild the bridge across Eighteen-Mile Creek.

As an alternate plan, the alignment of the road can be changed to cross below lock No. 10, station 1840, with a fixed span giving 90 feet clear headway. Estimates are made on this plan for a fixed bridge for both railroad and highway, together with the necessary changes of roads.

18. Provision should be made for a highway crossing at Olcott, either by steam ferry or a drawbridge. Estimates are based on the latter plan.

In addition to the above items the pipe system of the Tonawanda waterworks should be rearranged and the electric transmission cable running from Niagara Falls to Buffalo should be taken under the canal by tunnel.

In case the "B" line should be adopted, similar changes of highways and railroads would be necessary.

For the 21-foot channel the location of canal, lift and location of locks, location and character of structures, etc., are the same as for the 30-foot channel.

Estimates of quantities and cost of all work, including right of way, are given in the following tables:

TABLE NO. 6.—*Existing crossings—Tonawanda-Olcott route.*

| Location. | | Present grade. | Remarks. |
|---|---|---|---|
| Place. | Station. | | |
| *Railway.* | | | |
| International bridge. | 128 | 580.0 | Single-track railroad. |
| Tonawanda | 601 | 576.0 | Island street, Tonawanda. Single-track railroad and highway bridge. Draw span, 2 openings, 80 feet in clear each. |
| Do | 611-613 | 575.0 | New York Central and Hudson River R. R., Buffalo and Niagara Falls Branch, 9 tracks—2 main tracks and 7 sidings. |
| Do | 617 | 576.0 | Erie R. R., Buffalo and Niagara Falls Branch, 7 tracks—1 main track and 6 sidings. |
| Do | 627 | 575.0 | Single-track electric railway. |
| Do | 641 | 579.0 | Buffalo and Niagara Falls double-track electric railroad. |
| Do | 644 | 580.0 | Erie R. R., Lockport Branch, single track. |
| Do | 716 | 580.0 | New York Central and Hudson River R. R. Single track, Lockport Branch. |
| Do | 1238 | 610.8 | New York Central and Hudson River R. R. Double track, Lockport and Niagara Falls Branch. |
| Newfane station | 1808 | 318.0 | Rome, Watertown and Ogdensburg R. R. Single track. |
| *Highway.* | | | |
| North Tonawanda | 601 | 577.0 | Swing bridge across branch of Niagara River carrying single-track siding. |
| Do | 607 | 577.0 | Main street. Important. |
| Do | 627 | 575.0 | Vandervort street, single-track electric railroad. |
| Do | 641 | 579.0 | Paynes avenue, double track electric railroad. Besides these streets, Shenk street at 619, Oliver street at 623, Robinson street at 631, Keil street at 636, Miller street at 648, are crossed in North Tonawanda. |

TABLE NO. 6—*Existing crossings—Tonawanda-Olcott route*—Continued.

| Location. Place. | Station. | Present grade. | Remarks. |
|---|---|---|---|
| *Highway*—Continued. | | | |
| North Tonawanda | 668 | 575.0 | Nash road. Important. |
| | 689 | 575.0 | Martinsville road. Unimportant. |
| | 764 | | East avenue. Unimportant. |
| | 766 | 578.0 | Creek road. Important. |
| | 785 | 576.0 | Shawnee road. Not very much used. |
| | 832 | 579.0 | Town line road. Not very much used. |
| | 869 | 578.0 | County road. Unimportant. |
| | 966 | 590.0 | Cross road. Considerably used. |
| | 1018 | 590.0 | Pendleton road. Important. |
| | 1035 | 591.0 | Sulphur Springs road. Considerably used. |
| | 1093 | 589.0 | Hodgeville road. Not much used. |
| | 1149 | 596.0 | Buttermilk lane. Not much used. |
| | 1181 | 608.0 | Hinman road. Important. |
| | 1236 | 610.0 | Lockport road. Important. |
| | 1276 | 615.0 | Pekin road. Considerably used. |
| | 1293 | 573.0 | Crapsey road. Not important. |
| | 1310 | 530.0 | Gulf road. Not important. |
| | 1357 | 425.0 | Eldridge road. Not important. |
| | 1389 | 390.0 | Stone road. Important. |
| | 1454 | 370.0 | Turnpike road. Not very much used. |
| | 1535 | 360.0 | Swamp road. Unimportant. |
| | 1579 | 358.0 | Bennett road. Unimportant. |
| | 1661 | 346.0 | Unimportant. |
| | 1700 | 345.0 | Ide road. Considerable travel. |
| | 1782 | 325.0 | Not very much used. |
| | 1825 | 318.0 | West Creek road. Not very much used. |
| | 1887 | 253.0 | Lake road. Fixed span bridge across Eighteen-mile Creek. |

TABLE NO. 7.—*Location, cost, etc., of proposed bridges—Tonawanda-Olcott route.*

| Location. | Station. | Kind of bridge. | Number of tracks. | Swing or fixed. | Number of spans. | Thirty-foot channel. Total length. | Thirty-foot channel. Estimated cost. | Twenty-one-foot channel. Total length. | Twenty-one-foot channel. Estimated cost. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | *Feet.* | | *Feet.* | |
| International bridge. | 128 | Railway | 1 | Swing | 1 | 537½ | $146,686 | 517½ | $129,650 |
| North Tonawanda. | 607 | Highway | | do | 1 | 545 | 100,246 | 525 | 92,226 |
| Do | 613 | Railway | 2 | do | 1 | 550 | 231,063 | 530 | 203,427 |
| Do | 619 | do | 1 | do | 1 | 537½ | 143,016 | 517½ | 127,412 |
| Do | 625 | Highway | | do | 1 | 545 | 105,430 | 525 | 89,604 |
| Do | 641 | Highway and electric railway. | 2 | do | 1 | 550 | 158,466 | 530 | 139,938 |
| Do | 670 | Highway | | do | 1 | 545 | 105,430 | 525 | 89,604 |
| Sawyers Creek. | 765 | do | | do | 1 | 545 | 73,700 | 525 | 88,664 |
| Do | 849 | do | | do | 1 | 545 | 105,430 | 525 | 94,547 |
| Do | 1026 | do | | do | 1 | 567 | 67,574 | 547 | 63,446 |
| Do | 1181 | do | | do | 1 | 600 | 74,392 | 579 | 69,806 |
| Do | 1232 | Railway and highway. | 2 | do | 1 | 738 | 309,774 | 718 | *a* 294,069 |
| Do | 1302 | Highway | | do | 1 | 235 | 19,986 | 195 | 16,650 |
| Do | 1394 | do | | do | 1 | 235 | 19,986 | 195 | 16,650 |
| Do | 1614 | do | | do | 1 | 235 | 19,986 | 195 | 16,650 |
| Do | 1700 | do | | do | 1 | 567 | 67,574 | 547 | 63,446 |
| Do | 1840 | Railway and highway. | 1 | Fixed | 2 | 558 | 156,996 | 558 | *b* 156,996 |
| Olcott | 1888 | Highway | | Swing | 2 | 858 | 109,638 | 858 | *c* 109,638 |
| | | Bridges not over canal. | | | | | | | |
| Tonawanda | 607 | Highway | | do | 3 | 457½ | 33,091 | | 33,091 |
| Sawyers Creek. | 763 | do | | Fixed | 1 | 80 | 3,726 | | 3,726 |
| Total | | | | | | | 2,052,190 | | 1,899,240 |

*a* Double deck, draw span, two 63-foot girders. *b* Width C. to C. trusses, 40 feet.
*c* Two draw spans.

NOTE.—

| | Feet clear opening. |
|---|---|
| Highway bridges | 22 |
| Single-track bridges | 14 |
| Double-track bridges | 26 |
| Double-track double-deck bridges | 29 |

TABLE NO. 8.—*Tonawanda-Olcott route.*

LOCKS.

| Location. | | Length of level above. | Number. | Lift. | Kind. | | Elevation standard low water. | |
|---|---|---|---|---|---|---|---|---|
| Place. | Station. | | | | Single or double. | Individual or in flight. | Above lock. | Below lock. |
| | | *Miles.* | | | | | | |
| Buffalo | 88+97 | | 1 | 8.0 | Double | Individual | 574.3 | 566.3 |
| Lockport | 1299+97 | 22.9 | 2 | 40.0 | Single | do | 565.0 | 525.0 |
| Lockport flight | 1338+97 | .7 | 3 | 40.0 | Double | Flight | 525.0 | 485.0 |
| Do | | | 4 | 40.0 | do | do | 485.0 | 445.0 |
| Do | 1353+77 | | 5 | 40.0 | do | do | 445.0 | 405.0 |
| | 1394+97 | .8 | 6 | 40.0 | Single | Individual | 405.0 | 365.0 |
| | 1614+97 | 4.2 | 7 | 30.5 | do | do | 365.0 | 334.5 |
| Olcott flight | 1816+46 | 3.8 | 8 | 30.0 | Double | Flight | 334.5 | 304.5 |
| Do | | | 9 | 30.0 | do | do | 304.5 | 374.5 |
| Do | 1831+26 | | 10 | 30.0 | do | do | 374.5 | 344.5 |

COST.[a]

| Location. | Station. | Thirty-foot channel. | Twenty-one-foot channel. | Operating machinery. |
|---|---|---|---|---|
| Buffalo | | [b] $1,720,358 | [b] $1,135,413 | $100,000 |
| Lockport | 1299+97 | 1,455,666 | 910,420 | |
| Lockport flight | 1338+97 | 6,338,480 | 4,248,816 | |
| | 1394+97 | 1,388,916 | 874,665 | |
| | 1614+97 | 1,204,064 | 758,593 | |
| Olcott flight | 1816+46 | 5,448,315 | 3,672,694 | 600,000 |
| Total | | 17,553,779 | 11,600,601 | 700,000 |
| Operating machinery | | 700,000 | 700,000 | |
| Total | | 18,253,779 | 12,300,601 | |

[a] The cost is that of the structure complete, except the excavation.
[b] For standard low water Lake Erie regulated.

TABLE NO. 9—*Estimate for 30-foot channel—Tonawanda-Olcott route.*

NIAGARA RIVER (FROM STATION —85 TO STATION 601).

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *With regulating works.* | | | |
| Earth, cubic yards | 11,065,771 | $0.15 | $1,659,866 |
| Rock, dry, do | 90,014 | 1.00 | 90,014 |
| Rock, wet (in Lake Erie), do | 1,687,650 | 3.00 | 5,062,950 |
| Rock, wet (in Niagara River), do | 2,673,100 | 2.00 | 5,346,200 |
| Regulating works | | | 795,923 |
| Lock No. 1 | | | 1,720,358 |
| Operating machinery | | | 100,000 |
| Total | | | 14,776,311 |
| *Without regulating works.* | | | |
| Earth, cubic yards | 11,101,971 | .15 | 1,665,296 |
| Rock, dry, do | 90,014 | 1.00 | 90,014 |
| Rock, wet (Lake Erie), do | 2,227,900 | 3.00 | 6,683,700 |
| Rock, wet (Niagara River), do | 2,968,600 | 2.00 | 5,937,200 |
| Lock No. 1 | | | 1,726,838 |
| Operating machinery | | | 100,000 |
| Total | | | 16,203,048 |
| *Quantities common to both.* | | | |
| Retaining wall, cubic yards | 224,148 | 4.00 | 896,592 |
| Slope wall, square yards | 22,957 | 1.10 | 25,253 |
| Back fill, cubic yards | 223,702 | .25 | 55,926 |
| Timber cribs: | | | |
| Pine, feet B. M. | 756,860 | [a] 30.00 | 22,706 |
| Hemlock, do | 4,012,480 | [a] 23.00 | 92,287 |
| Oak, do | 48,000 | [a] 50.00 | 2,400 |
| Iron, pounds | 436,330 | .03 | 13,090 |
| Stone fill, cubic yards | 58,860 | .60 | 35,316 |
| Bridge, number | 1 | | 146,686 |
| Right of way, acres | 46 | 4,000.00 | 184,000 |
| Tunnel waterworks, linear feet | 1,000 | 30.00 | 30,000 |
| Total | | | 1,504,256 |

[a] Per 1,000 feet.

TABLE NO. 9.—*Estimate for 30-foot channel—Tonawanda-Olcott route*—Cont'd.

TOTAL COST NIAGARA RIVER (STATION —85 TO STATION 601).

| | |
|---|---|
| With regulating works: | |
| Excavation, etc | $14,776,311 |
| Retaining wall, etc | 1,504,256 |
| Total | 16,280,567 |
| Without regulating works: | |
| Excavation, etc | 16,203,048 |
| Retaining walls, etc | 1,504,256 |
| Total | 17,707,304 |

CANAL (STATION 601 TO STATION 1893+50).

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *Excavation.* | | | |
| In North Tonawanda (stations 601 to 667:) | | | |
| Earth ..... cubic yards | 2,982,425 | $0.20 | $596,485 |
| Rock ..... do | 32,500 | .70 | 22,750 |
| North Tonawanda to foot lock No. 5 (stations 667 to 1358+51): | | | |
| Earth ..... cubic yards | 17,173,906 | .18 | 3,091,303 |
| Hardpan ..... do | 4,085,995 | .30 | 1,225,799 |
| Rock, dry ..... do | 17,940,657 | .65 | 11,661,427 |
| Foot lock No. 5 to shore line Lake Ontario (stations 1538+31 to 1893+50): | | | |
| Earth ..... cubic yards | 7,988,363 | .18 | 1,437,905 |
| Hardpan ..... do | 923,400 | .30 | 277,020 |
| Rock, dry ..... do | 10,709,370 | .60 | 6,425,622 |
| Rock, wet ..... do | 1,096,550 | 1.75 | 1,918,963 |
| Walls, locks, etc.: | | | |
| Retaining wall ..... do | 358,784 | 4.50 | 1,614,528 |
| | 162,499 | 4.00 | 649,996 |
| Slope wall ..... square yards | 192,154 | 1.10 | 211,369 |
| | 87,461 | 1.45 | 126,818 |
| Back fill ..... cubic yards | 1,348,402 | .25 | 337,101 |
| Embankments ..... do | 632,350 | .15 | 94,853 |
| Crib walls: | | | |
| Pine ..... feet B. M. | 3,890,880 | *a* 30.00 | 116,726 |
| Hemlock ..... do | 19,423,350 | *a* 23.00 | 446,737 |
| Oak ..... do | 199,680 | *a* 50.00 | 9,984 |
| Iron ..... pounds | 1,951,870 | .03 | 58,556 |
| Stone fill ..... cubic yards | 303,768 | .30 | 91,130 |
| Locks 2 to 10, inclusive ..... number | 9 | ..... | 15,833,421 |
| Operating machinery ..... | ..... | ..... | 600,000 |
| Bridges ..... number | 19 | ..... | 1,905,504 |
| Railroad changes ..... | ..... | ..... | 199,640 |
| Diversion of streams ..... | ..... | ..... | 68,943 |
| Steam ferry ..... number | 1 | ..... | 20,000 |
| By-passes ..... | ..... | ..... | 39,585 |
| Right of way: | | | |
| Village property ..... acres | 190 | ..... | 1,246,960 |
| Farm property ..... do | 6,249 | ..... | 823,875 |
| Total ..... | ..... | ..... | 51,153,000 |

*a* Per 1,000 feet.

LAKE ONTARIO (STATION 1893+50 TO STATION 1919).

| | | | |
|---|---|---|---|
| *Excavation.* | | | |
| Earth ..... cubic yards | 8,475 | $0.15 | $1,271 |
| Rock ..... do | 431,400 | 1.75 | 754,950 |
| Breakwater ..... | ..... | ..... | 584,705 |
| Total ..... | ..... | ..... | 1,340,926 |

SUMMARY.

| | With regulating works. | Without regulating works. |
|---|---|---|
| Niagara River | $16,280,567 | $17,707,304 |
| Canal section | 51,153,000 | 51,153,000 |
| Lake Ontario | 1,340,926 | 1,340,926 |
| Total cost of route | 68,774,493 | 70,201,230 |

TABLE No. 10.—*Estimate for 21-foot channel—Tonawanda-Olcott route.*

NIAGARA RIVER (FROM STATION —38 TO STATION 601).

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *With regulating works.* | | | |
| Earth.....cubic yards.. | 5,110,104 | $0.15 | $766,516 |
| Rock, dry.....do.... | 13,219 | 1.00 | 13,219 |
| Rock, wet (in Lake Erie).....do.... | 419,850 | 3.00 | 1,259,550 |
| Rock, wet (in Niagara River).....do.... | 641,100 | 2.00 | 1,282,200 |
| Regulating works..... | ..... | ..... | 796,923 |
| Lock No. 1..... | ..... | ..... | 1,135,413 |
| Operating machinery..... | ..... | ..... | 100,000 |
| Total..... | ..... | ..... | 5,353,821 |
| *Without regulating works.* | | | |
| Earth.....cubic yards.. | 5,146,354 | .15 | 771,953 |
| Rock, dry.....do.... | 13,219 | 1.00 | 13,219 |
| Rock, wet (Lake Erie).....do.... | 718,100 | 3.00 | 2,154,300 |
| Rock, wet (Niagara River).....do.... | 923,250 | 2.00 | 1,846,500 |
| Lock No. 1..... | ..... | ..... | 1,141,893 |
| Operating machinery..... | ..... | ..... | 100,000 |
| Total..... | ..... | ..... | 6,027,865 |
| *Quantities common to both plans.* | | | |
| Retaining wall.....cubic yards.. | 224,148 | 4.00 | 896,592 |
| Slope wall.....square yards.. | 23,887 | 1.10 | 26,276 |
| Back fill.....cubic yards.. | 213,830 | .25 | 53,458 |
| Timber crib work: | | | |
| Pine.....feet B. M.. | 756,860 | *a* 30.00 | 22,706 |
| Hemlock.....do.... | 2,663,249 | *a* 23.00 | 61,945 |
| Oak.....do.... | 48,000 | *a* 50.00 | 2,400 |
| Iron.....pounds.. | 311,340 | .03 | 9,340 |
| Stone fill.....cubic yards.. | 41,010 | .60 | 24,606 |
| Bridge.....number.. | 1 | ..... | 129,650 |
| Right of way.....acres.. | 46 | 4,000.00 | 184,000 |
| Tunnel waterworks.....linear feet.. | 1,000 | 30.00 | 30,000 |
| Total..... | ..... | ..... | 1,440,973 |

*a* Per 1,000 feet.

TOTAL COST NIAGARA RIVER (STATION —38 TO STATION 601).

| | |
|---|---|
| With regulating works: | |
| Excavation, etc | $5,353,821 |
| Retaining walls, etc | 1,440,973 |
| Total | 6,794,794 |
| Without regulating works: | |
| Excavation, etc | 6,027,865 |
| Retaining walls, etc | 1,440,973 |
| Total | 7,468,838 |

CANAL (STATION 601 TO STATION 1893+50).

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *Excavation.* | | | |
| In North Tonawanda (stations 601 to 667): | | | |
| Earth.....cubic yards.. | 2,321,350 | $0.20 | $464,270 |
| North Tonawanda to foot of lock No. 5 (stations 667 to 1355+01): | | | |
| Earth.....cubic yards.. | 14,907,601 | .18 | 2,683,368 |
| Hardpan.....do.... | 3,044,977 | .30 | 913,493 |
| Rock.....do.... | 12,916,906 | .65 | 8,395,989 |
| Foot lock No. 5 to shore Lake Ontario (stations 1355+01 to 1893+50): | | | |
| Earth.....cubic yards.. | 6,902,568 | .18 | 1,242,462 |
| Hardpan.....do.... | 653,450 | .30 | 196,035 |
| Rock, dry.....do.... | 6,195,112 | .60 | 3,717,067 |
| Rock, wet.....do.... | 628,400 | 1.75 | 1,099,700 |
| Walls, locks, etc.: | | | |
| Retaining wall.....cubic yards | 300,505<br>48,168 | 4.50<br>4.00 | 1,352,273<br>192,672 |
| Slope wall.....square yards.. | 87,000<br>228,685 | 1.45<br>1.10 | 126,150<br>251,554 |
| Back fill.....cubic yards.. | 909,071 | .25 | 227,268 |
| Embankment.....do.... | 570,900 | .15 | 85,635 |

TABLE NO. 10.—*Estimate for 21-foot channel—Tonawanda-Olcott route*—Cont'd.

CANAL (STATION 601 TO STATION 1893+50)—Continued.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *Excavation*—Continued. | | | |
| Timber crib: | | | |
| Pine.....feet B. M.. | 4,330,980 | *a* $30.00 | $129,929 |
| Hemlock.....do.... | 14,683,520 | *a* 23.00 | 337,721 |
| Oak.....do.... | 218,160 | *a* 50.00 | 10,908 |
| Iron.....pounds.. | 1,565,154 | .03 | 46,895 |
| Stone fill.....cubic yards.. | 239,450 | .60 | 143,670 |
| Locks Nos. 2 to 10, inclusive | | | 10,465,188 |
| Operating machinery | | | 600,000 |
| Bridges.....number.. | 19 | | 1,769,590 |
| Railroad changes | | | 199,640 |
| Diversion of streams | | | 68,943 |
| Steam ferry.....number. | 1 | | 20,000 |
| By-passes | | | 39,585 |
| Right of way: | | | |
| Village property.....acres. | 190 | | 1,246,960 |
| Farm property.....do.... | 6,249 | | 823,875 |
| Total | | | 36,850,840 |

*a* Per 1,000 feet.

LAKE ONTARIO (STA. 1893+50 TO 1915).

| | | | |
|---|---|---|---|
| *Excavation.* | | | |
| Earth.....cubic yards.. | 8,550 | $0 15 | $1,283 |
| Rock.....do.... | 101,750 | 1.75 | 178,063 |
| Breakwater | | | 296,334 |
| Total | | | 475,680 |

SUMMARY.

| | With regulating works. | Without regulating works. |
|---|---|---|
| Niagara River | $6,794,794 | $7,468,838 |
| Canal section | 36,850,840 | 36,850,840 |
| Lake Ontario | 475,680 | 475,680 |
| Total cost of route | 44,121,314 | 44,795,358 |

## WATERWAY FROM LAKE CHAMPLAIN TO THE HUDSON RIVER AT TROY, DESIGNATED AS THE HUDSON RIVER DIVISION OF THE CHAMPLAIN ROUTE.

After the surveys were completed, and while the borings were being finished on the Niagara routes, the survey party was engaged in measuring the flood discharge of the Upper Mohawk River and other streams, which will be reported upon in detail in Part III.

After the flood measurements were completed the party proceeded to Troy, N. Y., on April 15, 1898. The borings were completed on the Niagara routes April 20, and the boring parties arrived at Troy on the 22d. Both the survey and boring parties immediately began work on the Hudson River division of the Champlain route.

This division begins at deep water in Lake Champlain opposite Port Henry and follows southerly up the lake to Whitehall, where it cuts across country southwesterly to the Hudson River near Fort Edward, following generally the valleys of Wood Creek and Bond

Creek. From Fort Edward to the State dam at Troy, which is the southern end of this division, the channel follows generally the bed of the Hudson River.

Below the Troy dam and to deep water at Germantown the surveys and borings were made by H. F. Dose, assistant engineer, and are designated as the Hudson River survey.

Lake Champlain marks the path of ancient glaciers which passed from the valley of the St. Lawrence to the valley of the Hudson. The foothills of the Adirondack Mountains, broken and steep, form its west shore, and the broken and rocky foothills of Green Mountains form its east shore, making the lake a deep, narrow trough cut through these mountains. The valley of Wood Creek and Bond Creek marks the old glacial path from Lake Champlain at Whitehall to the Hudson River at Fort Edward. It varies in width from a few hundred feet to 1 mile and has broken, rocky banks on each side. From Fort Edward to Troy the valley of the Hudson River is generally from one-quarter mile to 1 mile wide, with high, broken banks on the east and west, while the bed of the river is from 400 to 1,200 feet wide. The location follows the lowest ground from Lake Champlain to Troy and is generally parallel to the Champlain Canal, the several sections of which were opened from 1819 to 1823.

SURVEYS.

The surveys and examinations on this route were made in accordance with the instructions of your honorable Board to the assistant engineers, Appendix No. 9, and differed from the surveys of the Niagara route only in that soundings and borings were made in the river and lake and the notes were plotted in the field office as the work progressed.

In 1897 D. J. Howell, assistant engineer, began the surveys of the Mohawk River and, in connection with them, measured a base line up the Hudson River from the Troy dam to the Waterford bridge, and also made a shore-line survey of the river and established bench mark No. 7 at Waterford, elevation 30.62, which was used as the starting point for the levels on this line. The base line was started from station 246 + 77.46 of Mr. Howell's Hudson River base.

Between the Troy dam and Waterford the surveys consisted of soundings and borings in the river. All the topography on the left bank and about half of it on the right bank, also the base line and levels, were done by Mr. Howell. The levels between Mr. Howell's bench mark No. 1 and the Greenbush bench mark were run by H. F. Dose, assistant engineer. All elevations are referred to the Greenbush bench mark, elevation 14.73 above mean tide at New York.

The survey was begun at Troy the latter part of April, 1898, and completed to Port Henry in January, 1899, and covered a length,

measured along the center line of the located canal, of 97.5 miles, divided as follows:

| | Miles. |
|---|---|
| Hudson River from Troy to Fort Edward | 38.1 |
| Fort Edward to Whitehall | 23.4 |
| Lake Champlain from Whitehall to Port Henry | 36.0 |
| Total | 97.5 |

The nature and extent of the work required a larger force than had been employed on the Niagara routes. It was increased to meet the demands and the following organization effected:

1. A base-line party, composed of six men, which ran the base line and the duplicate line of levels and computed the coordinates of each transit station, after first adjusting the line between azimuth points. A copy of the coordinates and bench marks, together with sketches showing their location, was turned into the field office for distribution to the various stadia parties according to their location. When the base-line party got further ahead of the other work than was desired, it would take up stadia work. The levels were run with Buff & Berger wye levels and New York rods.

2. Two stadia parties, composed of six men each, who made the surveys, computed the coordinates of all stadia stations, reduced the elevations of all stadia shots, and plotted on a protractor sheet enough of the runs of each day to ascertain if the circuits closed within the required limits. Each party was given a portion of the line varying, according to the conditions of work, from 2 to 6 miles long, and were furnished with a copy of the base-line notes and the elevations of all bench marks.

3. A sounding party, composed of six men, who made soundings in the Hudson River from Troy to Fort Edward. The sounding ranges were put in about 300 feet apart, and soundings were taken 25 feet apart on these ranges. A copy of the base-line notes and locations and elevations of bench marks were furnished to this party, who staked out all ranges and determined the elevation of the water surface at each range and reduced the soundings to elevations. After completing the soundings to Fort Edward it took up stadia work, thus giving three stadia parties in addition to the assistance from the base-line party.

4. An office force for plotting and inking the topographic maps, varying from three to fifteen draftsmen and assistants, according to the conditions of the work. The maps are of the standard size, 28 inches by 40.5 inches, and are plotted to a scale of one in five thousand throughout the entire length of the line. These were matched for the purpose of locating the canal. In addition to these, maps were plotted on a larger scale for localities where the surface was very irregular.

Briefly, the method of mapping was to arrange the direction of the sheets so as to take in the greatest possible length of the line. Co-

ordinate lines 2,000 feet apart were then plotted, and the base-line stations and stadia stations were plotted by latitudes and departures. The stadia shots were plotted by azimuth and distance—one man called off and another plotted. The plotting was checked by the men reversing positions and repeating the operation. Each sheet was entirely completed by one draftsman. Two-foot contours are developed on each map.

5. A superintendent of borings had immediate charge of all borings. From Troy to Fort Edward one party, consisting of a foreman, three laborers, and a teamster with team, made the borings on land, and one party, consisting of a foreman and three laborers, made the borings in the river. After reaching Fort Edward the river party was changed to a land party, thus giving two land parties for the work between Fort Edward and Whitehall. For the land work the same plant was used as on the Niagara routes, and that for the river work only varied in having a catamaran from which to put down the holes. It was better adapted to the work than a scow, in that it could be taken apart and carried around the several dams in the river.

The surveys from Troy to Whitehall were made wide enough to cover any probable location of the canal. From Whitehall to Port Henry the base line and levels were run along the west shore of Lake Champlain and terminated on the "North base" of the Crown Point base line of the Coast Survey triangulation system 1872, lat. 44° 01′ 25.58″; long. 73° 25′ 49.55″.

The stadia survey extended from the shore of the lake to high ground, which was generally only a few hundred feet, and up the several streams to above elevation 100.

The surveys for this part of the work were completed October 21, 1898, and the borings to Whitehall October 17, 1898.

From Whitehall to Port Henry, a distance of 36 miles, the channel is located in Lake Champlain, which varies in width from a few hundred feet to over 6,000 feet. To make and locate soundings and borings in open water would require a large force and be very expensive, so it was decided to wait until the lake froze over and do this work on the ice, which was begun December 14, 1898, and completed January 21, 1899. The center line of the proposed location was run with transit, and soundings were made to the banks in the narrow parts and 400 feet right and left in the wide parts of the lake. In the open lake the sounding ranges were 200 feet apart, and the soundings were spaced 50 feet apart on these ranges. Between Whitehall and Putnam station the ranges were 100 feet apart and the soundings every 25 feet on these ranges.

### BORINGS.

On account of cold weather the machines used for making the borings could not be operated without protection for the pumps and water swivels. This was afforded by building a small shanty on

runners and moving it from hole to hole with a team. It was provided with a stove and trapdoors in the floor and roof, through which the drill rods could be passed. The men worked inside. Each of the three boring parties was provided with one of these shanties, and they were admirably adapted to the work for which they were used. There was no difficulty in working when the temperature was 30° below zero, while in the open air the pumps would freeze up when it was colder than 20° above zero.

### RESULTS OF STADIA WORK.

Taking the base line as standard and correct, and comparing the stadia surveys with it, the following results were obtained:

| | |
|---|---|
| Total number of stadia circuits run | 290 |
| Total length, in feet | 2,038,376 |
| Mean length of circuits, in feet | 7,944 |
| Mean error in latitude per circuit, in feet | 3.73 |
| Mean error in departure per circuit, in feet | 2.79 |
| Mean error of closure per circuit | 1 in 1,373 |
| Mean error of elevation per circuit, foot | 0.167 |

### COST OF WORK.

For the purpose of considering the cost of the work the line is divided into two parts, one taking in Lake Champlain and the other that part of the line between Whitehall and Troy.

The cost of the survey includes all labor, instruments, supplies, etc., connected with the field and office work for the survey, mapping, plans, and estimates and reduction of published charts.

The cost of borings includes labor, plant, and all other expenses connected therewith, except the cost of surveys for locating them and a portion of the assistant engineer's salary for general supervision.

For both surveys and borings all plant was considered as sunk when the work was completed and its cost proportioned to the various routes on which it was used.

*Lake Champlain.*

| | |
|---|---|
| Length of line, in miles | 36 |
| Cost of surveys | $5,636.00 |
| Cost of borings | $2,268.00 |
| Linear feet of borings | 20,169 |
| Cost per foot | $0.1124 |
| Cost borings per mile | $63.00 |
| Cost surveys per mile | $156.44 |

*Whitehall to Troy dam.*

| | |
|---|---|
| Length of line, in miles | 61.5 |
| Cost of surveys | $21,106 |
| Cost of borings | $4,905 |
| Linear feet of borings | 37,822 |
| Cost per foot | $0.1297 |
| Cost of borings per mile | $79.76 |
| Cost of surveys per mile | $343.19 |

The organization was somewhat broken and the cost of the work increased by the transfer of men to other parties and filling their places with new men. It is quite evident that the work could be done more cheaply by experienced men than by those new to the work.

After completing all field work, the boring parties, axmen, etc., were discharged and a force of ten engineers was retained to complete the maps and make final estimates. They reported to the Detroit office January 31, 1899, for this work.

### LOCATION.

The location of the channel was laid down on the topographic maps by your honorable Board. For the purpose of discussing the plans, character of excavation, etc., the line may be divided as follows:

1. Port Henry to Whitehall, which includes all work in that part of Lake Champlain.
2. Whitehall to Fort Edward, which includes all work across the divide between Lake Champlain and the Hudson River.
3. Fort Edward to the State dam at Troy, which includes all work in the Hudson River.

### PORT HENRY TO WHITEHALL.

In designing the channel and determining the grades of same through Lake Champlain, it is assumed that the low-water level will be regulated as indicated in Appendix No. 8, at elevation 100, and the high water will never be more than 102 feet above mean tide at New York. The grade of the 30-foot channel would then be at elevation 70, and of the 21-foot channel at elevation 79, and both level throughout.

To near Putnam station, station 1257, the proposed width is 600 feet, except for a short distance at Chipmans Point, where it narrows up to the present width between the rock bluffs on each side of the lake. From Putnam station to station 1864 the width is 450 feet, except at the "Narrows," where it is about 250 feet between the high rock bluffs on each side. From station 1864 to Whitehall, station 1957, it is 300 feet wide, except through the rock cut at the "Elbow," where it is of the standard canal section. The above widths and location apply to both the 30-foot and the 21-foot channels.

The material to be excavated in the lake is silt, sand, and rock and is classified in the estimates as earth and rock. Between Port Henry and a point about 2 miles south of Putnam station the earth is mostly sand, mixed with more or less silt and mud, but from this point to Whitehall it is a soft silt and mud, mixed with a small amount of sand, all of which has been washed into the lake by the floods of South Bay, Wood Creek, East Bay, and other small streams.

At low water the lake is a narrow stream winding through a low, flat marsh about 1,600 feet wide, with an average elevation of 95 feet; at high water the entire marsh is flooded. If the lake is regulated at elevation 100, this marsh would then be under 5 feet of water. It

would not support a high spoil bank, but it would probably be safe to assume that a bank 5 to 6 feet above low water would be stable. All of the earth to be excavated in the lake can be easily handled with a hydraulic dredge; and if this method is adopted for doing the work, ample spoil area requiring a maximum lift of less than 10 feet above water surface is available.

The earth slopes are 1 on 3 for all excavation in Lake Champlain, while they are estimated as 1 on 2 on all other parts of the line.

Rock is found at the following points:

At station 570, Larabees Point, Chipmans Point, and station 1404, opposite Cold Spring, small quantities of rock are found above the grade of the 30-foot channel, but it is all below the grade of the 21-foot channel. The rock at Larabees Point is shale or slate, and at the other places it is quartzite. About 1 mile north of Whitehall is a point of quartzite rock projecting into the lake. It is locally known as the "Elbow," and has an average elevation where the channel cuts through it of about 135, and the length of the cut is about 800 feet. A part of this rock is classified as wet excavation, but most of it is dry excavation.

Rock is also encountered in the harbor at Whitehall.

### WHITEHALL TO FORT EDWARD.

As before stated, it is assumed that the level of Lake Champlain will be regulated at elevation 100. Low water in the Hudson River at Fort Edward, where the canal enters, is at elevation 117.6 under present conditions; but if the river be deepened to 30 feet, this low water would be only slightly higher than the Fort Miller dam (115.1), which is 7.1 miles downstream. Two and seven-tenths miles below Fort Miller is the Northumberland dam, with a crest elevation of 102.5. The low-water level of the pool below this dam is about 85.

The divide between Lake Champlain and the Hudson River may be crossed in either of two ways:

1. By locking up at Whitehall to the level of the Hudson River and then making the grade of the channel level to Fort Miller.

2. By making a through cut on the level of the lake channel to the Northumberland dam.

The first plan would involve supplying water to the high level for lockage at Whitehall and at Fort Miller. This can be done by constructing a system of reservoirs on the head waters of the Hudson. It would also involve the construction of two additional locks. On the other hand there would be a large saving in the quantity of excavation. In case this plan be adopted, it would be best to raise the crest of the dam at Fort Miller to an elevation of 118, which would reduce the excavation and not flood the valley of the Hudson at high water.

The second plan would involve a greater amount of excavation for the channel, but would save the expense of providing a water supply and the cost of two locks. In this case the water for lockage would

be brought from the St. Lawrence River through Lake Champlain and down to the Hudson River on a continuous down grade, requiring but little expense over the cost of constructing the canal. The crest of the dam at Northumberland would be cut down to the level of Lake Champlain—elevation 100. Ships would be saved the time of locking at Whitehall and at Fort Miller.

A preliminary estimate indicates that the cost of the two plans is about the same; and since the second plan gives a more certain and unlimited water supply, as well as a channel that can be more quickly navigated, it was decided to base the estimates on the low-level cut.

The alignment is shown on plates 51 and 52 and is the same for both the 30-foot and 21-foot channels. Rock appears above grade at Whitehall for a distance of about 1,500 feet, dips below grade at station 1972, and appears again at station 2290, 6.3 miles south of Whitehall, and continues above grade to station 2523, just south of Fort Ann. All of this rock is a hard quartzite, irregularly stratified, and dips to the east. It contains many vertical cracks or seams and is hard to drill, but breaks well when blasted. Between Fort Ann and Fort Edward rock is found above grade in several places, and is a hard shale or slate when covered with earth or water, but breaks up into flakes and splinters when excavated and exposed to the air and eventually becomes a clay soil; but when exposed to the air in its natural bed, it decidedly, though slowly, disintegrates. It breaks up well by blasting and is easily drilled.

The material overlying the bed rock is generally soft clay mixed with sand, but pockets of pure sand are found just north of Fort Ann and between Whitehall and Comstocks. No bowlders are found, and but very little gravel mixed with the earth. In fact, it is good material to excavate with a hydraulic dredge, though the lift may be too great in the deepest cuttings for this method.

The streams crossed are Wood Creek, Granville River, Halfway Creek, and Bond Creek. On leaving Lake Champlain, the channel enters the valley of Wood Creek, which is a sluggish stream winding through a low valley, and follows it with frequent crossings for 16.5 miles to station 2830. One-half mile north of this point it should be taken into the canal. Its elevation is 138 feet, or 38 feet above the proposed water level.

The Granville River is crossed 1.7 miles south of Whitehall and is 7 feet above the canal. Halfway Creek is crossed just south of Fort Ann, halfway between Whitehall and Fort Edward, and is 28 feet above the canal.

Separate gaugings of these streams could not be had, but they all enter the lake through one channel and have a combined low-water flow of 300 cubic feet per second and a high-water flow of 7,000 cubic feet per second. These streams can be taken into the canal by letting them down over a dam to the level of the canal and constructing a basin of sufficient cross section to let them enter at a low velocity.

By cutting a diversion channel about 1,200 feet long Wood Creek can be taken into the canal on a solid rock foundation at station 2855.

It will be seen on plate 52 that the Champlain Canal enters Wood Creek at Fort Ann and the two streams then become one and the same to station 2260, a distance of 5.2 miles. They pass through the narrow gorge about 4 miles, from station 2300 to station 2516, and it is evident that the canal can not be maintained while the new channel is being excavated if the work is done in the dry. In fact, the only way to do this part of the work in the dry is to construct a dam across the head of the gorge and excavate a channel along the line of the canal to carry the waters of Halfway Creek and Wood Creek to the Hudson River at Fort Edward. In case this part of the work is excavated with hydraulic dredges, these streams would furnish a water supply for pumping. There are also several small streams crossed on this reach of the canal, but they can all be cared for at small expense and need not be considered in detail.

It will be necessary to change the alignment of the Delaware and Hudson Canal Company Railroad at the following points:

| From station— | To station— | Distance. |
|---|---|---|
| | | *Feet.* |
| 1847 | 1911 | 6,400 |
| 2127 | 2190 | 6,300 |
| 2337 | 2362 | 2,500 |
| 2470 | 2507 | 3,700 |
| 2525 | 2557 | 3,200 |
| 2640 | 2730 | 9,000 |
| Total | | [a]31,100 |

[a] Equals 5.7 miles.

Near station 3110 it is proposed to build a guard lock and by-pass to serve the double purpose of regulating the low-water flow from the lake to the Hudson River and the high-water flow from the river to the lake. The lock could be located at any point near the Hudson, but the site is selected on account of affording rock foundation.

### FORT EDWARD TO STATE DAM AT TROY.

This part of the canal is located generally in the bed of the Hudson River, but makes such cut-offs at the bends as are necessary to give good alignment and may more properly be called canalized river.

It involves hydraulic problems somewhat different from those met with on the other parts of the lines, in that navigation must be maintained during the times of extreme low and extreme high water, the range of which is great.

For the purpose of showing the conditions which govern the high and low water in the Hudson River a tabulated statement is given of the dams existing across the river, together with the distance above the State dam at Troy, the average elevation of crest, and, as near as can be ascertained, the elevation of high and low water at several points.

TABLE NO. 11.

| Location. | Above Troy dam. | Length of dam. | Average elevation of crest. | Date of high water. | Elevation of high water. | Elevation of low water. | Range between high and low water. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | *Miles.* | *Feet.* | | | | | | |
| State dam at Troy | 0.0 | 1,100 | 13.5 | Mar. 1, 1896 | 23.4 | 14.2 | 9.2 | High water caused by ice gorge; dam submerged. |
| Do | | | | 1861 | 28.4 | | | High water caused by ice gorge. Information from McElroy's notes. |
| 3 miles above Troy | 3.0 | | | 1861 | 30.0 | | | Do. |
| Do | 3.0 | | | 1894 | 29.6 | 15.4 | 14.2 | High water caused by ice gorge. Authority, Waterford bridge tender. |
| 4.9 miles above Troy. | 4.9 | | | 1894 | 33.5 | 16.8 | 16.7 | High water caused by ice gorge. Authority, Frank W. Van Fleck. |
| 9 miles above Troy | 9.0 | | | 1869 | 45.1 | 31.6 | 13.5 | Authority, Mr. Hasbroock. Mark on willow tree. |
| Hudson River Power Transmission Co.'s dam. | 9.4 | 708 | 48.0 | Apr. 19, 1896 | 54.9 | 48.9 | 6.0 | High water computed. Dam built 1897-98. Assumed part of water is passing through sluices. |
| The Duncan Co.'s dam. | 11.5 | 794 | 64.5 | do | 72.7 | 65.3 | 7.4 | Authority, The Duncan Co.'s gauge readings. |
| Just below Stillwater dam. | | | | 1850 | 83.9 | 76.8 | 7.1 | Caused by ice gorge. Authority, McElroy's notes. |
| Stillwater dam | 13.9 | 820 | 83.6 | Apr. 19, 1896 | 91.5 | 84.0 | 7.5 | High water computed. Angular alignment and irregular crest. |
| 0.7 miles above Stillwater dam. | 14.6 | | | do | 93.2 | 84.1 | 9.1 | Authority, Wm. Toban, Stillwater, N. Y. |
| 0.15 miles above Stillwater dam. | 14.05 | | | 1844 | 92.6 | | | Caused by ice gorge. Authority, McElroy's notes. |
| 2.7 miles above Stillwater dam. | 16.6 | | | Apr. 19, 1896 | 93.5 | 84.1 | 9.4 | Caused by ice gorge. Authority, W. N. Hill, Bemis Heights, N. Y. |
| 4.4 miles above Stillwater dam. | 18.3 | | | do | 95.3 | 84.2 | 11.1 | Caused by ice gorge. Authority, Mrs. Joseph Holmes, Bemis Heights, N. Y. |
| 6.1 miles above Stillwater dam. | 20.0 | | | Apr. 26, 1895 | 96.2 | 84.2 | 12.0 | Caused by ice gorge. Authority, G. A. Ensign, C. E. Mark, and photograph. |
| 10.4 miles above Stillwater dam. | 24.3 | | | 1896 | 98.3 | 84.4 | 13.9 | Nail in tree by. |
| Schuylerville Bridge. | 26.3 | | | 1896 | 99.2 | 84.6 | 14.6 | Authorities, Abraham De Riddle, east end bridge; F. B. Pannock, west end bridge; also, photograph. All agree. |
| State dam at Northumberland | 28.1 | 810 | 102.5 | 1896 | 110.3 | 103.3 | 7.0 | High water computed. Irregular crest and angle in dam. |
| Do | 28.1 | | | | 111.2 | | | Authority, McElroy's notes. |
| 0.4 miles above State dam at Northumberland. | 28.5 | | | Apr. 19, 1896 | 112.2 | 103.5 | 8.7 | Authority, Warner, C. E.; also, photograph by him. |
| Do | 28.5 | | | | 111.4 | | | Authority, McElroy's notes. |

TABLE No. 11—Continued.

| Location. | Above Troy dam. | Length above dam. | Average elevation of crest. | Date of high water. | Elevation of high water. | Elevation of low water. | Range between high and low water. | Remarks. |
|---|---|---|---|---|---|---|---|---|
| | *Miles.* | *Feet.* | | | | | | |
| Just above Fort Miller dam, east side. | 31.0 | ..... | ..... | ..... | 122.6 | ..... | ..... | Authority, McElroy's notes. |
| Fort Miller dam. | 31.0 | 710 | 115.1 | 1896 | 122.5 | 115.9 | 6.6 | High water computed. |
| 1.6 miles above Fort Miller dam. | 32.6 | ..... | ..... | 1896 | 127.0 | 116.3 | 10.7 | Authority, Marlow Dickinson. Approximate mark. |
| Do | 32.6 | ..... | ..... | 1869 | 129.0 | 116.3 | 12.7 | Do. |
| 2 miles above Fort Miller dam. | 33.0 | ..... | ..... | ..... | 131.2 | 116.5 | 14.7 | Authority, McElroy's notes. |
| 3.3 miles above Fort Miller dam. | 34.3 | ..... | ..... | 1896 | 127.9 | 116.5 | 11.4 | Authority, Seth W. Bristol. |
| 5.5 miles above Fort Miller dam. | 36.5 | ..... | ..... | 1896 | 132.0 | 116.9 | 15.1 | Authority, Geo. P. Cook. Correct within a tenth or two. |
| Do | 36.5 | ..... | ..... | 1869 | 135.0 | 116.9 | 18.1 | Authority, Geo. P. Cook. Definite mark. |
| 7.3 miles above Fort Miller dam. | 38.3 | ..... | ..... | 1896 | 132.7 | 117.6 | 15.1 | Name not taken. |
| East end Fort Edward railroad bridge. | 38.5 | ..... | ..... | ..... | 134.8 | ..... | ..... | Authority, McElroy's notes. |
| At Glens Falls Paper mills. | 38.9 | ..... | ..... | 1896 | 132.9 | 120.0 | 12.9 | Authority, superintendent of paper mills. Definite. |
| Glens Falls Paper Co.'s dam at Fort Edward. | 39.0 | 588 | 140.3 | Apr. 19, 1896 | 148.56 | 140.7 | 7.86 | High water from paper company's gauge readings, Jan. 1, 1896, to date |

NOTE 1.—The distances are measured along the center line of the proposed channel from the Troy dam to Fort Edward, and not along the river channel as it now exists.
NOTE 2.—All elevations are corrected to refer to Greenbush bench mark, elevation 14.73 above mean tide at New York.

It is evident that the dams control the elevation of the high water at the points where they are located, and the elevation at other points is the slope in the river from these points to the dam below, plus the depths over the dams, so that the range between the low and the high water is greater at all other points than at the dams.

Since the control of the flood waters is an important factor in designing the channel, it might be well to inquire as to the period that such data cover. Samuel McElroy, civil engineer, made a survey of the Hudson River from Fort Edward to Troy, in 1866, for the State of New York. In his report, dated January 1, 1867, he gave the elevation of the high and low waters at several points, and states that they are the "greatest known in one hundred years." However, many of them must be eliminated on account of the changes made in the river since that time. New dams have been built and the crests of the old ones have been changed, so that the elevation of the water then and now would not in many places be the same for a given volume of flow. The high waters noted by him at

Schuylerville, Crockers Reefs, and Fort Edward would probably be about the same now for the same volume of flow. Since this survey was made two notable high waters have occurred—April, 1869, and April 19, 1896—the former being from 1½ to 3 feet higher than the latter. The high-water marks given by Mr. McElroy are lower than those of 1869 and higher than those of 1896. It is probably safe to say that these records cover a period of at least sixty years.

The high waters in the vicinity of Troy have been caused by ice gorges below the State dam, and do not, therefore, represent normal conditions. These floods rise rapidly in two to three days, and recede in about the same time.

The normal low-water flow and low-water level are difficult to determine under present conditions. Water wheels are installed at the dams with a much greater capacity than the low-water flow of the river, and as a result the water in the pools above the dams is frequently drawn down from 1 to 2 feet below the crest of the dam. If the wheels stop at such times, there will be no flow below the dam until the pool above is filled to a level above the crest, thus giving a period of no flow in the river at that point, and if the wheels start up again the flow will be greater than the normal supply to the river.

Under these conditions the low-water level may vary 2 feet or more while the normal supply remains constant. Taking the list of dams given in the above table and also the several dams above Fort Edward, it will be seen how difficult it would be to select a time for making measurements when the river was discharging its normal low-water volume at any given point.

However, it is not important for the purposes of this report to know the exact low-water flow except that it shows there will be little or no slope in the proposed channel at low-water stages. There would be a very flat slope when the discharge is double the extreme low-water flow. This condition fixes the grade of the proposed channel as level from one dam to another to give the required low-water depth throughout.

For the flood stages of the river it is assumed that the mean velocity should not exceed 4 feet per second to afford safe navigation and protection to the banks of the channel. It is also desirable to limit at all points the fluctuations between low and high waters to a minimum. Starting with a low-water level at Northumberland and entering the river below the Troy dam at tide level, there is a difference of level of 100 feet to be overcome by locks and dams.

If the present dams can be maintained at their present elevations, it is evident that the industries depending on the power at the dam sites will be disturbed the least possible amount. Fortunately the locations and elevations of the dams are such that this general plan can be followed except for the one at Fort Miller.

This must be entirely taken out in order to carry the level of Lake Champlain to Northumberland, where the first dam and lock would

be put in after leaving the lake. At each of the dams below this point it is proposed to have a lock and to maintain dams at about the present elevation. It is desirable to build dams with as great a length of crest as possible, so as to limit the range between low and high waters in the levels above them.

The cross section of the proposed waterway must be of a size to not only afford good navigation, but to carry the flood waters with a mean velocity not greater than 4 feet per second, or 2.73 miles per hour. According to Table No. 11, the flood of 1869 is the greatest recorded, and is such as may not occur oftener than once or twice in a century, and it would be better to let the current exceed this velocity when it occurs than to enlarge the channel. The flood of 1896 is such as may occur, say, once in fifteen years, and the channel should be designed to take care of it without damage to the banks or to navigation.

The Duncan Company has gauge readings of the depth of water over the crest of its dam from 1886 to date, and the Glens Falls Paper Company has readings from January, 1896, to date. They show that the ordinary spring flood is about 50 per cent of the maximum floods; also that the maximum floods do not remain above the ordinary for a period of more than from four to six days and are not at the extreme stage longer than from one to two days.

The above data give the height of the water at various points, but it is also important to know the volume of flow in order to determine the height to which it would rise on the new dams, the slope in the channel, and the velocity of the current. For this purpose the flood of April, 1896, will be taken as one which the channel should carry with a mean velocity not exceeding 4 feet per second, and for any flood greater than this the velocity would be allowed to increase. It would obviously be better to repair any damage done and to suffer any delay to navigation than to make the expenditure for constructing a channel of the required larger dimensions, especially as the only damage that may be done will be to delay navigation for from two to four days. The evidence points to the conclusion that there has occurred only one flood in the past one hundred years as large as that of 1869.

From the gauge readings on the dams at Fort Edward and at Mechanicville the volume of flow may be computed for April 19, 1896. The crest of the former dam is 588 feet long and the depth of water over it was 8.16 feet, while the crest of the latter dam is 794 feet long and the water over it was 8.33 feet.

The usual formula for computing the flow over dams or weirs is that deduced from the Lowell experiments by James B. Francis, and is—

$Q = C\,L\,h^{\frac{3}{2}}$ in which,

Q = discharge in cubic feet per second.

L = length of dam in feet.

$h$ = depth of water over dam.

C = a coefficient.

The value of C varies through a wide range for different depths of water and for different cross sections of the dam or weir used. Most experiments have been with small volumes of water and with a depth over the weir of less than 2 feet. The most complete experiments of this character were made by the eminent French engineer, M. Bazin. These experiments were extended with large volumes of water and depth over the crest as great as 6 feet, under the direction of your honorable Board at the Cornell Hydraulic Laboratory, and are fully reported on in Appendix No. 16. While none of the forms used have exactly the same cross section as the Fort Edward dam, Cornell experiment No. 6 comes the nearest to it and gives 3.63 as the value of C for a depth of 6 feet. Taking into account the roughness of the structure, it would be conservative to take C = 3.5 for a depth of 8.16 feet on the Fort Edward dam, which would give a discharge of 47,700 cubic feet per second on April 19, 1896.

The section of dam used in Cornell experiment No. 18 is the same as the Duncan Company's dam at Mechanicville, except the latter has an apron on the downstream side, which would have the effect, if any, of increasing the value of C. In this experiment 3.44 was obtained as the value of C for a depth of water of 6 feet.

Using this coefficient for a depth of 8.33 feet on the Duncan dam, we get a discharge of 65,800 cubic feet per second for April 19, 1896.

Having fixed the volume of flow at these two points, it then becomes necessary to determine, as near as may be, the flow at the proposed location of other dams, to compute the flood heights over their crests, and the slopes and velocities in the new channel when constructed. Between Fort Edward and Northumberland, Moses Kill and Snook Kill enter the Hudson, and the additional watershed will furnish also a small amount of water. The flow at Northumberland is taken as 49,000 cubic feet per second. Batten Kill, Fish Creek, and other small streams are assumed to increase this to 52,000 at Stillwater. Just below Stillwater the Hoosick River enters and increases the flow to 65,800 at the Duncan dam. The distribution of this increased flow is probably not correct, but it is near enough to the truth for the purpose of this report. No other important streams enter the Hudson until the Mohawk is reached just above Troy.

In fixing the size of the cross sections it was assumed that 17,000 cubic feet per second would be turned toward Lake Champlain through the by-pass at the Fort Edward guard lock. In this way the volume to be provided for just below Fort Edward is reduced to 32,000 cubic feet per second, and at the other points mentioned by a like amount. It would probably not be necessary to pass the full 17,000 cubic feet per second toward Lake Champlain for more than one day, and three days would likely be the longest period that it would be necessary to divert any flow in that direction during any one flood. Table No. 12 shows the location, elevation, and length of crest of the proposed dams, together with the regulated high-water discharge and the eleva-

tions of high water above and below the dams as they will occur after the channel is constructed. The new dams are to be of the ogee section, and 4 feet is taken as the value of C when the depths are 6 for computing the discharge over them.

Bazin's experiment No. 193 gives C = 4.55 for a head of 1.26 feet on this form of dam. Cornell experiment No. 19 gives C = 3.675 for a head of 6 feet, but this is not the ogee form. For computing the flood depths over crest, C = 4.01 is used. In computing the slopes and velocities in the channel, the formula $V = C\sqrt{rs}$ is used. C is derived from Kutter's formula by assigning a value of 0.30 to *n*.

*Dam No. 1.*—Located at Northumberland. The old dam is to be taken out and replaced by a concrete dam of the ogee section.

*Dam No. 2.*—Located at Stillwater, and is to be of concrete and ogee section.

*Dam No. 3.*—The Duncan Company's dam at Mechanicville. It is to be lengthened from 794 feet to 860 feet, but otherwise unchanged.

*Dam No. 4.*—The Hudson River Power Transmission Company's dam, 2 miles below Mechanicville. It is of the ogee section, 708 feet long, and built in 1897. It is to remain unchanged. Under the flood heads about 14,000 cubic foot-seconds flow through the 16 sluices and the water wheels, leaving 51,800 cubic foot-seconds to flow over the crest of the dam.

*Dam No. 5.*—Located 1 mile above Waterford, and is to be a new dam of the ogee section.

*Dam No. 6.*—The State dam at Troy, which has an elevation of 13.5, but the low-water level is raised to 15 by the use of flash boards. No changes are required in it.

TABLE NO. 12.—*Dams.*

CHAMPLAIN ROUTE, HUDSON RIVER DIVISION.

[Thirty-foot channel.]

| Dam No. | Location station. | Crest. | | Elevation of water surfaces. | | | | Estimated discharge, cubic feet per second. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| | | Length. | Elevation. | Above dam. | | Below dam. | | | |
| | | | | High. | Low. | High. | Low. | | |
| 1 | 3720 | 800 | 100 | 104.6 | 100 | 90.4 | 85 | 32,000 | |
| 2 | 4473 | 900 | 85 | 89.6 | 85 | 71.6 | 65 | 35,000 | |
| 3 | 4582 | 860 | 65 | 71.5 | 65 | 53.6 | 48 | 48,800 | |
| 4 | 4710 | 708 | 48 | 53.3 | 48 | 35.9 | 30 | 34,800 | 14,000 through sluices and turbines. |
| 5 | 4920 | 1,000 | 30 | 35.3 | 30 | a23.3 | 15 | 48,800 | |
| 6 | 5208 | 1,100 | 15 | 22.5 | 15 | ..... | 0 | ..... | High water estimated. |

a The high-water elevations given at dams Nos. 2 and 5 are below the locks, instead of immediately below the dam.

NOTE.—Elevation high-water station 3197=106.9.

The observed high waters which have occurred at Troy have been caused by ice gorges below the dam, and the high waters which have occurred independent of ice gorges are affected by the backwater, so that no reliable data exist from which to compute the flood discharge

of the river at this point. If the channel is deepened below the dam to 30 feet and 300 feet wide, it is not probable that these gorges will occur, and, in addition to this, the height of the backwater will be reduced. The flood of 1896 gave a depth of 9.9 feet over the crest of the dam. It is probable that this would not be greater than 9 feet under the new conditions, giving an elevation of 22.5 feet when the flashboards are down. This is the elevation assumed in the above table.

Locks are located near each of the above dams. They are all single locks of the standard design, with rock foundations. The locations of the locks and also of the dams are the same for both 21-foot and 30-foot channels. Continuing the numbering as brought from Lake Ontario down the St. Lawrence River and to Lake Champlain, the first one on this division would be No. 6. The numbers continue successively downstream.

Table No. 13 gives a statement of the locks to be built.

TABLE NO. 13.—*Locks.*

| No. | Station.[a] | Length of level above, in miles. | Elevation, low-water surface. Above. | Below. | Lift. | Remarks. |
|---|---|---|---|---|---|---|
| 6 | 3112 | 127.4 | 100 | 100 | ..... | Guard lock at Fort Edward. |
| 7 | 3727 | 11.5 | 100 | 85 | 15 | At Northumberland. |
| 8 | 4486 | 14.4 | 85 | 65 | 20 | At Stillwater. |
| 9 | 4585 | 1.75 | 65 | 48 | 17 | Just above Mechanicville. |
| 10 | 4722 | 2.43 | 48 | 30 | 18 | 2 miles below Mechanicville. |
| 11 | 4999 | 3.72 | 30 | 15 | 15 | 1 mile above Waterford. |
| 12 | 5215 | 4.09 | 15 | 0 | [b]15 | At Troy dam. |

COST.[c]

| Lock No. | Thirty-foot channel. | Twenty-one-foot channel. | Operating machinery. |
|---|---|---|---|
| 6 | $777,799 | $453,116 | $100,000 |
| 7 | 1,002,988 | 632,554 | 100,000 |
| 8 | 1,054,289 | 660,829 | 100,000 |
| 9 | 1,024,458 | 646,329 | 100,000 |
| 10 | 1,041,229 | 656,329 | 100,000 |
| 11 | 976,674 | 617,229 | 100,000 |
| 12 | 1,001,658 | 630,629 | 100,000 |
| Total | 6,879,095 | 4,297,015 | 700,000 |
| Operating machinery | 700,000 | 700,000 | ..... |
| Total | 7,579,095 | 4,997,015 | ..... |

[a] The stationing given above is at the middle of the lock. Water power for driving the operating machinery can be developed at the site of each dam.
[b] The lift of this lock was made 15 feet to provide for a minimum low water.
[c] The cost is for the lock structure complete, except excavation.

The grades of the 21-foot and 30-foot channels are, respectively, 21 feet and 30 feet below the water surface given in the above table.

ALTERNATE PLAN.

While the tabulated estimates in this report are based on fixed dams with height of crest the same as that of the proposed low-water level, a part of the line could be treated in a different way at a great

saving in cost of construction. The elevation of the Troy dam at present is 13.5, and the low-water level is raised to 15 by the use of flashboards.

By substituting for them a movable form of dam this could be increased to 18 feet without injury to any existing industries along the river. At times of high water the movable part of the dam could be lowered so as to keep the flood stage at or below the present high-water level. This would require 3 feet less cutting back to lock No. 11. Similarly, dam No. 5 could be raised 4 feet, dam No. 4, 4 feet, and dam No. 3, 5 feet without decreasing the head now existing at each of them. In fact, the available head would be greater than at present. In addition to this, the fixed crest could be placed lower than at present, and thus decrease the high-water level. Dam No. 2 could not be raised without decreasing the head at dam No. 1. Dam No. 1 could not be raised, for the reason that its level is fixed with reference to the level of Lake Champlain; and the guard locks at Fort Edward could not be used to hold the waters back, since the supply is needed from Lake Champlain for lockage. However, it may appear cheaper to raise dam No. 2 and pay the damage due to the decreased head at dam No. 1.

To raise dams Nos. 3, 4, 5, and 6 as indicated above would make a saving for the 30-foot channel of approximately $5,230,000 in excavation and lock and retaining-wall construction. From this must be deducted the increased cost of constructing the dams, $40,000, making a net saving of $5,190,000. For the 21-foot channel the net saving would be $4,774,000, less $40,000, equals $4,734,000.

These changes would also change the lifts of locks Nos. 8, 9, 10, 11, and 12 for both the 30-foot and the 21-foot channels, shown in the following table:

TABLE No. 14.—*Locks for alternate plan.*

| Lock No. | Station location. | Elevation of low water | | Lift of lock. | Remarks. |
|---|---|---|---|---|---|
| | | Above. | Below. | | |
| 8 | 4486 | 85 | 70 | 15 | At Stillwater. |
| 9 | 4585 | 70 | 52 | 18 | Just above Mechanicville. |
| 10 | 4722 | 52 | 34 | 18 | 2 miles below Mechanicville. |
| 11 | 4999 | 34 | 18 | 16 | 1 mile above Waterford. |
| 12 | 5215 | 18 | 00 | 18 | At Troy dam. |

If dam No. 2 be raised 3 feet, the lift of lock No. 7 would be changed from 15 to 12 feet and lock No. 8 from 15 to 18 feet. The net saving, exclusive of damage to water power, would be $6,837,000, minus the increase in cost of dams, for the 30-foot channel, and $6,072,000, minus the increase in cost of dams, for the 21-foot channel.

This alternate plan seems worthy of consideration.

STABILITY OF THE CHANNEL.

The upper Hudson does not carry a large amount of sediment, and there is but little evidence of caving banks or "silting up." A comparison of the profiles made from the survey of Mr. McElroy in 1866 with those made from the survey in 1898 (thirty-two years later) shows that there have been only slight changes in the bed of the stream in that time, although there have occurred in this interval the extreme high waters of 1869 and 1896. Since the high-water slope and the velocity of the currents will be less in the new channel than in the present river, we may safely conclude that the channel will be stable and require but little excavation to maintain the navigable depth.

The material to be excavated is classified under the heads of rock and earth, there being no hardpan on this line. The rock is a slate or shale, in irregular layers which dip sharply to the east, firm and hard when in its original bed, but disintegrates rapidly when broken up and exposed to the air. It is more easily drilled than limestone, and breaks up readily under the blast. The earth from Northumberland to Stillwater, a distance of 14 miles, is an alluvial deposit composed principally of soft clay and sand, while that on the rest of the line is somewhat harder, but composed of the same materials. All of it can be easily excavated with hydraulic dredges. For the entire length of the line from Port Henry to Troy there is no hardpan and very little gravel or bowlders, making the earth of a class that is easy to excavate.

The estimate of quantities of excavation is based on the standard sections of channel adopted by your honorable Board, except for Lake Champlain, where the side slopes are made 1 on 3 instead of 1 on 2, as in other cases, on account of the soft material through which the cut is made.

As already stated, the widths of channel adopted are: From Port Henry to Putnam station, 600 feet; from Putnam station to 1 mile north of Whitehall, 450 feet; from 1 mile north of Whitehall to Whitehall, 300 feet, except in the cut through the "Elbow," where it is of standard canal section; in Whitehall from station 1957 to station 1971 is 200 feet wide; from Whitehall to the Hudson River at Fort Edward, standard canal section; from Fort Edward to Northumberland the 30-foot channel is of the standard canal section, but the 21-foot channel is made 300 feet wide to carry the flood waters of the river; from Northumberland to Troy both channels are made 300 feet wide.

BRIDGES.

Tables Nos. 15 and 16 give certain data in regard to the bridges now existing across Lake Champlain and the Hudson River; also the railway and highway crossings which are encountered between Whitehall and Fort Edward.

TABLE No. 15.—*Existing bridges, Champlain route, Hudson River division.*

| Location. | | Kind of bridge. | Fixed or swing. | Number of tracks. | Number of spans. | Total length of bridge. | Total width of bridge. | Elevation of floor. | Remarks. |
|---|---|---|---|---|---|---|---|---|---|
| Place. | Stations. | | | | | | | | |
| | | | | | | *Feet.* | *Feet.* | | |
| Addison Junction. | 783 | Railroad | Swing | 1 | 1 | 300 | | 107.5 | Pontoon draw. Pile trestle 2,270 feet long. Used by Rutland R. R. |
| Whitehall | 1958 | Highway | Fixed | | 2 | 200 | 27 | R. 122.3<br>L. 135.0 | Wooden Howe trusses. Crosses Wood Creek and Champlain Canal. |
| Do | 1963 | Footbridge | do | | 2 | 180 | 12 | 135 | Iron truss bridge over Wood Creek and Champlain Canal. |
| Do | 1967 | Highway | do | | 3 | 285 | 28 | 132 | Iron bowstring trusses. Crosses Wood Creek and Champlain Canal. |
| Do | 1987 | do | do | | 1 | 140 | 20 | 123 | Wooden Howe trusses. Crosses Wood Creek. |
| Do | 1994 | Railroad | do | 1 | 1 | 150 | | 125 | Pratt truss bridge over Wood Creek. Used by Rutland Branch, Delaware and Hudson R. R. |
| Northumberland. | 3705 | Highway | do | | 11 | 577 | 19 | | Wooden bridge owned by State and used as change bridge for canal. |
| Do | 3737 | Electric railroad. | do | 1 | 17 | 800 | | | Bridge and railway in process of erection. |
| Clarks Mills | 3756 | Highway | do | | 3 | 450 | 16 | 86 | Riveted Warren truss steel bridge. This bridge will not be interfered with by proposed canal. |
| Schuylerville. | 3821 | do | do | | 14 | 814 | 19 | 96.0 | Wooden Howe trusses on piers of small stone. Is a toll bridge, owned by private company. |
| Stillwater | 4466 | do | do | | 9 | 616 | 20.5 | 96.0 | 8 bowstring iron spans and 1 Pratt truss span. Toll bridge owned by private company. Not interfered with by proposed canal. |
| Mechanicville. | 4554 | Railroad | do | 2 | 10 | 1,257 | 20 | 118.5 | 9 iron combination Pratt & Warren truss spans and 1 plate girder span. Used by Fitchburg R. R. Good cut stone piers. Bridge of old type. |
| Do | 4618 | Highway | do | | 3 | 524 | 27.5 | 60.5 | Iron Warren truss spans. Toll bridge owned by private company. |
| Waterford | 5051 | Highway and electric railroad. | do | 2 | 3 | 798 | 31 | 37.4 | Wooden arched truss bridge, built in 1803. Toll bridge owned by private company. |
| Lansingburg | 5116 | do | Swing | 2 | 5 | 822 | 37 | 39.3 | Draw span 129 feet long C. to C. end pins. 3 through Warren trusses. Toll bridge owned by private company. |

TABLE No. 16.—*Existing highway crossings, Champlain route, Hudson River division.*

| Station. | Place. | Remarks. |
|---|---|---|
| 2237 | | Not much traveled. |
| 2302 | | |
| 2345 | Comstocks P. O | Of considerable importance. |
| 2467 | Flat Rock | Do. |
| 2553 | Fort Ann | Important crossing. |
| 2640 | | Not very much used. |
| 2761 | Smiths Basin | Important. |
| 2872 | | Not much used. |
| 2907 | | Do. |
| 2940 | | Do. |
| 3002 | Dunhams Basin | Important. |
| 3137 | Fort Edward | Do. |
| 3166 | ....do | Considerably used. |
| 3179 | ....do | Do. |
| 3187 | ....do | Important. |

Some of these highway crossings may be consolidated without material injury to the traveling public, which would be through an agreement with the parties interested. At the present time an electric railway is being built along the valley of the Hudson River from Stillwater to Northumberland, where it crosses the river below the State dam. This railway can be taken across the canal on the bridge to be built at station 3756. For the purpose of determining the number and character of bridges which must be built or reconstructed it is assumed that they will be needed at the locations given in Table No. 17.

TABLE No. 17.—*Location, cost, etc., of proposed bridges, Hudson River division, Champlain route.*

| Station. | Location. | Kind of bridge. | Number of tracks. | Swing or fixed. | Number of spans. | Thirty-foot channel. | | Twenty-one-foot channel. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Total length. | Estimated cost. | Total length. | Estimated cost. |
| 757 | Addison Junction. | Railway | 1 | Swing | 4 | 977½ | $174,676 | 957½ | $174,676 |
| 1968 | Whitehall | Highway | | do | 1 | 475 | 50,002 | 475 | 50,000 |
| 1987 | do | do | | do | 1 | 545 | 105,430 | 525 | 89,604 |
| 1994 | do | Railway | 1 | do | 1 | 537½ | 161,810 | 517½ | 133,496 |
| 2289 | Comstocks | Highway | | do | 1 | 545 | 73,338 | 525 | 71,894 |
| 2467 | Flat Rock | do | | do | 1 | 693 | 75,456 | 579 | 70,218 |
| 2553 | Fort Ann | do | | do | 1 | 545 | 112,882 | 525 | 96,186 |
| 2646 | | do | | do | 1 | 545 | 88,264 | 525 | 91,912 |
| 2762 | Smiths Basin | do | | do | 1 | 545 | 118,708 | 525 | 102,144 |
| 2857 | | do | | do | 1 | 565 | 80,387 | 541 | 75,665 |
| 3000 | Dunhams Basin. | do | | do | 1 | 545 | 123,976 | 525 | 109,914 |
| 3112 | Fort Edward | do | | do | 1 | 255 | 18,633 | 255 | 18,633 |
| 3180 | do | do | | do | 1 | 545 | 116,850 | 525 | 98,608 |
| 3757 | Clarks Mills | Highway and electric railway. | 1 | do | 1 | 565 | 71,533 | 541 | 66,504 |
| 4466 | Stillwater | Highway | | do | 1 | 565 | 68,769 | 541 | 64,800 |
| 4554 | Mechanicville | Railway | 2 | do | 1 | 550 | 203,383 | 530 | 191,093 |
| 4618 | do | Highway | | do | 1 | 545 | 84,774 | 525 | 83,304 |
| 4721 | | do | | do | 1 | 235 | 19,986 | 195 | 16,650 |
| 5051 | Waterford | Highway and electric railway. | 2 | do | 1 | 550 | 128,208 | 530 | 120,774 |
| 5116 | Troy (Twelth street). | do | 2 | do | 2 | 650 | 145,980 | 630 | 138,536 |
| 3757 | Clarks Mills | Highway and electric railway.[a] | 1 | Fixed | 3 | 450 | 19,330 | 450 | 19,330 |
| | Total cost | | | | | | 2,042,355 | | 1,881,051 |

[a] Bridge not over canal.

| | Feet clear opening. |
|---|---|
| Highway bridges | 22 |
| Single-track railway bridges | 14 |
| Double-track railway bridges | 26 |

RIGHT OF WAY.

Without specifying in detail, the right of way estimated is intended to be sufficient for the prism of the channel and for spoiling the material excavated by any method that is suitable for the work. Through towns it is narrowed up to small limits, but in the farming districts a generous width is provided.

The estimates of quantities and cost of all work, including right of way, are given in Tables Nos. 18 and 19.

TABLE NO. 18.—*Champlain route, Hudson River division.*

[Estimate, 30-foot channel.]

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *Lake Champlain (station 0 to station 1957).* | | | |
| Excavation: | | | |
| Earth, wet ..... cubic yards | 47,717,339 | $0.12 | $5,726,081 |
| Rock, quartzite, dry ..... do | 409,064 | .75 | 306,798 |
| Rock, quartzite, wet ..... do | 45,983 | 2.50 | 114,958 |
| Rock, shale, wet ..... do | 26,100 | 2.00 | 52,200 |
| Right of way: | | | |
| Village property ..... acres | 120 | ..... | 33,000 |
| Farm property ..... do | 192 | ..... | 5,050 |
| Railroad changes ..... | ..... | ..... | 61,500 |
| Bridge ..... number | 1 | ..... | 174,676 |
| Total ..... | ..... | ..... | 6,474,363 |
| *Whitehall to Fort Edward (station 1957 to station 3197).* | | | |
| Excavation: | | | |
| Earth, dry ..... cubic yards | 79,839,083 | .15 | 11,975,862 |
| Rock, dry, quartzite ..... do | 6,569,002 | .75 | 4,926,752 |
| Rock, dry, shale ..... do | 2,179,083 | .60 | 1,307,450 |
| Retaining walls, etc.: | | | |
| Retaining wall ..... do | 93,865 | 4.00 | 375,460 |
| Slope wall ..... square yards | 506,290 | 1.10 | 556,919 |
| Back fill ..... cubic yards | 353,970 | .25 | 88,493 |
| Timber cribs: | | | |
| Pine ..... feet B. M. | 932,865 | *a* 30.00 | 27,986 |
| Hemlock ..... do | 3,973,940 | *a* 23.00 | 91,401 |
| Oak ..... do | 53,280 | *a* 50.00 | 2,664 |
| Iron ..... pounds | 423,582 | .03 | 12,707 |
| Stone fill ..... cubic yards | 65,620 | .60 | 39,372 |
| Right of way: | | | |
| Village property ..... acres | 477 | ..... | 782,500 |
| Farm property ..... do | 5,594 | ..... | 559,400 |
| Railroad changes ..... | ..... | ..... | 63,000 |
| Bridges ..... number | 12 | ..... | 1,125,776 |
| Entrance of streams ..... | ..... | ..... | 55,010 |
| Gates for by-pass ..... | ..... | ..... | 52,115 |
| Lock No. 6 ..... | ..... | ..... | 777,799 |
| Operating machinery ..... | ..... | ..... | 100,000 |
| Total ..... | ..... | ..... | 22,920,626 |
| *Hudson River (station 3197 to station 5235).* | | | |
| Excavation: | | | |
| Earth, dry ..... cubic yards | 14,027,058 | .15 | 2,104,059 |
| Earth, wet ..... do | 25,355,910 | .20 | 5,071,182 |
| Rock, dry ..... do | 7,197,489 | .60 | 4,318,493 |
| Rock, wet ..... do | 19,350,931 | 2.00 | 38,701,862 |
| Walls, etc: | | | |
| Retaining walls ..... do | 159,619 | 4.50 | 718,286 |
| Slope walls ..... square yards | 380,155 | 1.45 | 551,225 |
| Back fill ..... cubic yards | 659,934 | .25 | 164,984 |
| Crib walls: | | | |
| Pine ..... feet B. M. | 6,564,270 | *a* 30.00 | 196,928 |
| Hemlock ..... do | 9,440,730 | *a* 23.00 | 217,137 |
| Oak ..... do | 270,640 | *a* 50.00 | 13,532 |
| Iron ..... pounds | 1,373,766 | .03 | 41,213 |
| Stone fill ..... cubic yards | 202,008 | .60 | 121,205 |

*a* Per 1,000 feet.

TABLE NO. 18.—*Champlain route, Hudson River division*—Continued.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *Hudson River (station 497 to station 7235)*—Continued. | | | |
| Right of way: | | | |
| Village property ..... acres | 185 | ..... | $1,397,700 |
| Farm property ..... do | 5,209 | ..... | 636,700 |
| Bridges ..... number | 8 | ..... | 741,943 |
| Dams Nos. 6, 7, 8, 10 ..... | 4 | ..... | 139,568 |
| Locks ..... | 6 | ..... | 6,101,206 |
| Operating machinery ..... | ..... | ..... | 600,000 |
| Entrance of Hudson ..... | ..... | ..... | 118,186 |
| Steam ferry ..... | ..... | ..... | 20,000 |
| Total ..... | ..... | ..... | 61,975,490 |

SUMMARY.

| | |
|---|---|
| Lake Champlain ..... | $6,474,263 |
| Whitehall to Fort Edward ..... | 22,920,626 |
| Hudson River ..... | 61,975,499 |
| Total ..... | 91,370,388 |

TABLE NO. 19.—*Champlain route, Hudson River division.*

[Estimate, 21-foot channel.]

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *Lake Champlain (station 0 to station 1957).* | | | |
| Excavation: | | | |
| Earth, wet ..... cubic yards | 18,999,386 | $0.12 | $2,279,926 |
| Rock, quartzite, dry ..... do | 334,716 | .75 | 251,037 |
| Rock, quartzite, wet ..... do | 11,195 | 2.50 | 27,988 |
| Right of way: | | | |
| Village property ..... acres | 120 | ..... | 33,000 |
| Farm property ..... do | 192 | ..... | 5,050 |
| Railroad changes ..... | ..... | ..... | 61,500 |
| Bridge ..... number | 1 | ..... | 174,676 |
| Total ..... | ..... | ..... | 2,833,177 |
| *Whitehall to Fort Edward (station 1957 to station 3197).* | | | |
| Excavation: | | | |
| Earth, dry ..... cubic yards | 68,780,484 | .15 | 10,317,073 |
| Rock, dry, quartzite ..... do | 4,743,531 | .75 | 3,557,648 |
| Rock, dry, shale ..... do | 1,220,480 | .60 | 732,288 |
| Walls, etc.: | | | |
| Retaining wall ..... do | 62,102 | 4.00 | 248,408 |
| Slope wall ..... square yards | 546,849 | 1.10 | 601,534 |
| Back fill ..... cubic yards | 221,877 | .25 | 55,469 |
| Timber crib: | | | |
| Pine ..... feet B. M. | 943,425 | *a*30.00 | 28,303 |
| Hemlock ..... do | 3,000,880 | *a*23.00 | 69,020 |
| Oak ..... do | 53,280 | *a*50.00 | 2,664 |
| Iron ..... pounds | 337,557 | .03 | 10,127 |
| Stone fill ..... cubic yards | 50,515 | .60 | 30,309 |
| Right of way: | | | |
| Village property ..... acres | 477 | ..... | 782,500 |
| Farm property ..... do | 5,594 | ..... | 559,400 |
| Railroad changes ..... | ..... | ..... | 63,000 |
| Bridges ..... number | 12 | ..... | 1,008,276 |
| Entrance of streams ..... | ..... | ..... | 55,010 |
| Gates for by-pass ..... | ..... | ..... | 45,385 |
| Lock No. 6 ..... | ..... | ..... | 453,116 |
| Operating machinery ..... | ..... | ..... | 100,000 |
| Total ..... | ..... | ..... | 18,717,590 |
| *Hudson River (station 497 to station 7235).* | | | |
| Excavation: | | | |
| Earth, dry ..... cubic yards | 10,722,835 | .15 | 1,608,425 |
| Earth, wet ..... do | 18,023,672 | .20 | 3,604,734 |
| Rock, dry ..... do | 4,650,489 | .60 | 2,790,293 |
| Rock, wet ..... do | 12,344,104 | 2.00 | 24,688,208 |

*a* Per 1,000 feet.

TABLE NO. 19.—*Champlain route, Hudson River division*—Continued.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| *Hudson River (station 3197 to station 5235)*—Continued. | | | |
| Walls etc.: | | | |
| Retaining walls ..... cubic yards.. | 61,140 | 4.50 | 275,130 |
| Slope walls ..... square yards.. | 468,555 | 1.45 | 679,405 |
| Back fill ..... cubic yards.. | 367,788 | .25 | 91,947 |
| Crib walls: | | | |
| Pine ..... feet B. M.. | 6,463,670 | *a* 30.00 | 193,910 |
| Hemlock ..... do ... | 9,116,940 | *a* 23.00 | 209,690 |
| Oak ..... do ... | 266,320 | *a* 50.00 | 13,316 |
| Iron ..... pounds.. | 1,332,656 | .03 | 39,980 |
| Stone fill ..... cubic yards . | 195,036 | .60 | 117,022 |
| Right of way: | | | |
| Village property ..... acres.. | 185 | ..... | 1,397,700 |
| Farm property ..... do.... | 5,209 | ..... | 636,700 |
| Bridges ..... | 8 | ..... | 700,991 |
| Dams ..... | 4 | ..... | 139,568 |
| Locks ..... | 6 | ..... | 3,843,899 |
| Operating machinery ..... | ..... | ..... | 600,000 |
| Entrance of Hudson ..... | ..... | ..... | 118,186 |
| Steam ferry ..... | ..... | ..... | 20,000 |
| Total ..... | ..... | ..... | 41,769,104 |

*a* Per 1,000 feet.

SUMMARY.

| | |
|---|---|
| Lake Champlain | $2,833,177 |
| Whitehall to Fort Edward | 18,717,530 |
| Hudson River | 41,769,104 |
| Total | 63,319,811 |

## FLOOD-DISCHARGE MEASUREMENTS OF THE UPPER MOHAWK AND OTHER STREAMS.

In accordance with your instructions, on March 1, 2, and 3, 1898, I made a reconnoissance of the Mohawk River and tributaries from Rome to Little Falls, and of Fish Creek from Lake Oneida to Taberg, with the view of determining at what points approximate flood measurements could be easily and cheaply made during the spring of 1898. The time allowed to prepare for and take the observations precluded the use of current meters and similar methods for determining the velocity of the current.

As a result of this preliminary study it was decided to take the measurements at points and by methods as follows:

1. The Mohawk River at Little Falls. A masonry dam, locally known as the "Middle dam," exists across the river. It is about 10 feet high, and all the water not used by the mills passes over its crest. By measuring the depth of water flowing over it and adding to this the amount of water used by the mills the total flow could be computed at this point.

2. The West Canada Creek at Herkimer. About 2 miles above Herkimer a timber and rock fill dam exists across the stream, and it was decided to use the depth of flow over it for computing the discharge of the stream, but later it was found that the dam farther up the stream, at Middleville, was better adapted for the purpose and it was used instead of the one at Herkimer.

3. The Sauquoit Creek, which empties into the Mohawk at New Hartford about 2 miles above Utica. At this point the measurements were made over the dam, as at Little Falls.

4. The Oriskany Creek, which empties into the Mohawk at Oriskany. A dam was used at this place also.

5. Nine-Mile Creek, which empties into the Mohawk opposite and above Oriskany. A dam was used at this place.

6. The Mohawk River at Rome. Near the city is a masonry dam, but at times of high water it is drowned out and evidently could not be utilized. About 2 miles above Rome, at Ridge Mills, a suitable dam was found over which the greater part of the flood waters passed, and the rest flowed through two openings under highway bridges. This point was selected for making the measurements of flow in the Mohawk at Rome.

7. Fish Creek and Wood Creek, which empty into Lake Oneida at Sylvan Beach. No dams exist across either of these streams over which the flow could be measured. Wood Creek is a sluggish stream, winding through a low, flat swamp, and at no place are the banks high enough to hold the waters within the prism of the stream, and no measurements of it were undertaken. Just below the junction of the east branch and the west branch of Fish Creek is the only place between this point and Lake Oneida where the ordinary floods are confined within the banks of the stream, and the extreme floods spread over the bottom lands here. This is about 1 mile below the town of Taberg, and about 9 miles above the outlet of the stream. This point was selected for making the measurements, and the velocity of the current was determined by the use of rod floats.

The various members of the party arrived at Rome from the Niagara routes on March 8, 9, and 10, and were placed as follows:

Little Falls, George F. Anderson; West Canada Creek, P. H. Ashmead and Curtis Hill; Sauquoit Creek, J. W. Jenkins; Oriskany Creek, H. H. Lotter; Mohawk River at Ridge Mills, H. F. Dose and M. W. Tenny; Nine-Mile Creek, R. McD. Geraty; Fish Creek, H. C. Goodrich and A. A. Conger.

The warm weather existing at this time caused the snow to melt rapidly, with the result that the maximum flood stage in the streams was reached March 12. Rains on that night prolonged but did not increase the flood period to the 14th, which gave ample time to gage the depth of water flowing over the dams. The surveys of the various dams were made after the waters receded. The floods of the Mohawk, West Canada Creek, Nine-Mile Creek, and Fish Creek were the highest which had occurred for several years, but were probably considerably less than the maximum which has occurred; while the flow in Oriskany Creek and in the Sauquoit Creek was much below the ordinary spring floods.

The middle dam at Little Falls was built in 1892, and this flood was the greatest which has occurred since the dam was built.

The discharge of the various streams was not finally worked up, but all notes were turned over to the Water Supply Division, and the results are included in the report of Mr. George W. Rafter, Appendix No. 16.

REPORT ON RESULTS OF TWO LINES OF LEVELS RUN FROM THE GREENBUSH BENCH MARK (OPPOSITE ALBANY, N. Y.) TO LAKE ONTARIO.

These two lines of levels were run by six different parties and the results of the work are set forth in this report.

The first line considered starts at the Lake Survey bench mark at Greenbush, N. Y., with elevation 14.73 feet[1] above mean tide at New York, and runs up the Hudson River to the mouth of the Mohawk River and follows the valley of the Mohawk to Rome. From Rome it runs to Lake Oneida and down the valleys of the Oneida and Oswego rivers to the Lake Survey bench mark A at Oswego, N. Y.

The other line runs from the Greenbush bench mark, elevation 14.73, up the Hudson River to Fort Edward, and then crosses the divide to Whitehall, at the head of Lake Champlain, and then continues down the shore of the lake to the Crown Point light-house. From this point to Cooperville, near Rouse Point, the levels are transferred by water levels. From Cooperville to Cape Vincent, at the foot of Lake Ontario, the levels were run with wye levels and precise levels.

The two lines were connected through Lake Ontario by water levels, using Oswego and Cape Vincent as the points for making gauge readings.

OSWEGO-MOHAWK ROUTE.

All levels on this line were run with Buff & Berger wye levels in opposite directions, and the means of the two runs were used in determining the elevations of the bench marks. The line was run by three separate parties and the work of each will be considered in regular order, beginning at Greenbush and ending at Oswego, on Lake Ontario.

First. In August, 1898, levels were run, under the direction of H. F. Dose, assistant engineer, from bench mark 1, at Troy, N. Y., elevation 21.85 feet, to the bench mark on gristmill at Greenbush, making its elevation 14.50 feet, or 0.23 foot lower than the adopted elevation of 14.73 feet for this bench mark. Therefore we have $21.85 + 0.23 = 22.08$, which is the elevation of bench mark 1, at Troy, corresponding to elevation 14.73 of the Greenbush bench mark.

Second. In October, 1897, levels were run, under the direction of D. J. Howell, assistant engineer, from United States Lake Survey bench mark 6, elevation 49.69, on lock No. 4 of Erie Canal, to bench mark 1,

[1] See pages 70 and 71, Report of United States Deep Waterways Commission, 1896.

on Congress Street Bridge, at Troy. The elevation of bench mark 1 thus established was 21.85. But the elevation of this bench mark, as determined by Mr. Dose, starting with elevation of 14.73 of the Greenbush bench mark, is 22.084, a difference of 0.23 foot. Since the levels were not run connecting bench mark 1 with the Greenbush bench mark until August, 1898, Mr. Howell continued his levels from bench mark 1 (using elevation 21.85) up the Mohawk Valley to bench mark 88, at Herkimer, N. Y., making its elevation 389.18 feet. Therefore we have 389.18+0.23=389.41 feet for the elevation of bench mark 88, corresponding to elevation 14.73 of the Greenbush bench mark. This line of levels was run in connection with the topographic survey, and was completed in October, 1898.

Third. A line of levels was run in connection with the topographic survey, under the direction of A. J. Himes, assistant engineer, from United States Lake Survey bench mark A, at Oswego, to bench mark 88, at Herkimer. It was begun in October, 1897, and completed in July, 1898. Starting with elevation 251.96 of bench mark A, an elevation of 388.52 was obtained for bench mark 88. But, as stated above, the elevation of bench mark 88, referred to 14.73 of the Greenbush bench mark, is 389.408 feet, a difference of 0.89 foot. Therefore we have 251.96+0.89=252.85 for the elevation of bench mark A at Oswego.

Using elevation 251.96 for bench mark A, United States Assistant Engineer Churchill has determined the elevation of the zero of the United States gauge at Oswego as 244.18 feet. Therefore we have 244.18+0.889=245.07 for the elevation of the zero of this gauge referred to 14.73 of the Greenbush bench mark. Readings of the water surface were taken at 7 a. m., 12 noon, and 6 p. m. on this gauge from July 27, 1898, to August 6, 1898, both inclusive. There were no great fluctuations during the period, the extreme at Oswego being from 1.47 to 1.60 feet. A mean of all of these readings gives the water surface as 1.53 feet above the zero of the gauge, or elevation 246.60 feet.

### CHAMPLAIN ROUTE.

The levels on this route were run by several different parties using different methods, and will be considered in regular order from Troy, N. Y., to Lake Ontario.

First. Wye levels from Troy, N. Y., to Crown Point light-house.

Second. Water levels from Crown Point light-house through Lake Champlain to Kings Bay, at Cooperville, N. Y.

Third. Wye levels from Rouse Point bench mark via Cooperville to Hogansburg, on the St. Lawrence River.

Fourth. Precise levels from Hogansburg to Cape Vincent, at the foot of Lake Ontario.

TROY TO CROWN POINT LIGHT-HOUSE.

This line was run in connection with the topographic survey, under the direction of C. L. Harrison, assistant engineer, with Buff & Berger wye level in opposite directions, and the means of the two runs were used in determining the elevations of the bench marks. It was begun in May, 1898, and completed in September, 1898.

Starting at Troy from bench mark 1, elevation 21.85, as noted above, and running via Fort Edward and Whitehall to Crown Point light-house, bench mark 231 was established, with elevation 130.585. Therefore we have 130.585+0.23=130.815 for the elevation of bench mark 231, corresponding to 14.73 of the Greenbush bench mark. Connection was also made with United States Coast Survey bench mark 36, on lock No. 23 of Champlain Canal, at Whitehall, making its elevation 104.55 feet, and with United States Coast Survey bench mark 39, at Putnam Station, making its elevation 107.615.

WATER LEVELS THROUGH LAKE CHAMPLAIN.

The levels were transferred by water through Lake Champlain from Crown Point light-house to Kings Bay at Cooperville in January, 1899, at a time when the entire lake was frozen over from Whitehall to Rouse Point, excepting about 10 miles of the "broad lake," near Burlington, Vt. Crown Point is at the north end of the narrow and shallow part of the lake, which extends southward to Whitehall. Kings Bay is 6 miles south of Fort Montgomery and near the north end of the wide and deep part of the lake, which extends southward to Crown Point. These two points were selected for making the transfer, as they were not so liable to be affected by slopes due to flow of water through the lake and the piling up of water due to wind action as points situated in the narrow part of the lake.

The transfer of the levels was made in the following manner:

On the dock at Crown Point light-house and on the bridge pier at Cooperville index points were established. By means of float gauges the distance of the water surface below the index points was measured at ten-minute intervals, beginning at 8.40 p. m., January 13, and ending at 8 p. m., January 15, making a continuous set of readings, covering a period of nearly forty-eight hours. The extreme fluctuation of the water surface during this time was 0.22 foot at Crown Point gauge and 0.21 foot at Cooperville gauge. The index point of gauge at Crown Point was connected by spirit levels with the bench mark on light-house, and the index point of gauge at Cooperville was connected with bench mark 1 on bridge pier. Aneroid barometers were read hourly at each station, but these readings were not used in working up the final results, because the correction due to the difference of atmospheric pressure at the two points was less than the probable error in the barometers themselves. From these observations we have:

| | |
|---|---|
| Bench mark on Crown Point light house | 130.815 |
| Index point Crown Point gauge | 98.761 |
| Mean distance water surface below index point | 3.128 |
| Elevation water surface at Crown Point | 95.633 |
| Elevation water surface at Cooperville | 95.633 |
| Elevation index point above mean water surface | 1.675 |
| Elevation index point of Cooperville gauge | 97.308 |
| Elevation bench mark 1 above index point | 5.730 |
| Elevation bench mark 1 at Cooperville | 103.038 |

If the barometer correction, 0.045 foot, be applied, this elevation would become 103.083, but it is neglected for the reasons given above.

In August, 1898, a duplicate line of wye levels was run, under the direction of Frank P. Davis, assistant engineer, from the Rouse Point bench mark, using elevation 110.06, as established by the Coast Survey in 1882, to Cooperville, and establishing bench mark 1, with elevation 104.147, which is 1.109 feet higher than obtained above. We have, therefore, 110.06—1.109 = 108.951 for the new elevation of the Rouse Point bench mark.

The elevation 110.06 of the Rouse Point bench mark was transferred in 1882 by water levels through Lake Champlain from Putnam station to Rouse Point. Since the new determination of this is 1.109 feet lower, it might be well to compare the gauge readings taken at Fort Montgomery and at other points on the lake. From January 1 to January 15 the gauge readings were not taken at Fort Montgomery, but gauges were read at Whitehall and at Putnam station at the same time readings were taken at Crown Point and Cooperville—January 14 and 15. But on the 15th the flood waters (caused by the rains on the 14th) from Wood Creek and the Granville River increased the slope in the lake from Whitehall to Putnam station about 0.3 foot. Taking the readings on the 14th, when there was very little water flowing into the lake at Whitehall, we have the following results:

Elevation water surface at—

| | Feet. |
|---|---|
| Whitehall | 96.01 |
| Putnam station | 95.90 |
| Crown Point | 95.68 |

showing a slope of 0.11 foot from Whitehall to Putnam station and 0.22 foot from Putnam station to Crown Point. The gauge at Whitehall was set from bench mark 36, elevation 104.55, and the gauge at Putnam was set from bench mark 39, elevation 107.615. The elevations of these benches as determined by the Coast Survey are: No. 36, 104.71 feet, and No. 39, 108.46 feet. If these elevations had been used in setting the gauges, then we would have had:

Water surface at—

| | Feet. |
|---|---|
| Whitehall | 96.17 |
| Putnam station | 96.745 |

making a fall in the water surface from Putnam station to Whitehall of 0.575 foot. This is impossible, as the direction of the flow is from Whitehall toward Putnam station.

The difference, then, of 1.109 feet between this (108.951) and the former (110.06) determination of the Rouse Point bench mark seems to be distributed as follows:

Difference in levels—

| | Feet. |
|---|---|
| Greenbush to Whitehall | 0.160 |
| Whitehall to Putnam station | .685 |
| Slope in lake from Putnam to Crown Point | .220 |
| Transferring levels across lake | .044 |
| Total | 1.109 |

During the progress of the surveys gauges were established and read at Crown Point village, about 6 miles south of Crown Point light-house, and at Whitehall for short periods.

In May, 1899, Frank P. Davis, assistant engineer, ran a checked line of levels from Rouse Point bench mark, 108.951, to the United States engineers' gauge at Fort Montgomery, determining the elevation of its zero as 93.50 feet. Reducing the readings of this gauge to elevations for periods at which we have readings at other points in the lake, we have:

| Date. | | Mean water surface. | | | |
|---|---|---|---|---|---|
| From— | To— | Crown Point village. | Whitehall. | Fort Montgomery. | Difference. |
| Sept. 13, 1898 | Oct. 20, 1898 | 94.77 | | 94.68 | 0.09 |
| Dec. 2, 1898 | Dec. 21, 1898 | | 95.68 | 95.34 | .34 |
| Jan. 16, 1899 | Jan. 27, 1899 | | 96.10 | 95.68 | .42 |

The readings September 13 to October 20 were taken when the lake was open and affected more or less by the winds, those in December when the lake was partially frozen over, and those in January when the lake was almost entirely frozen over. The slope observed January 14, 1899, at low water, when the lake was frozen over from Whitehall to Crown Point, was 0.33 foot. If this be applied, we have 0.09 foot for the slope from Crown Point light-house to Fort Montgomery. These gauge readings indicate that there can be no substantial error in the levels from Whitehall to the Rouse Point bench mark. If the old elevations of the bench marks at Whitehall and Rouse Point were used to determine the water surface at these points, there would be a slope at low water of about 0.53 foot from Fort Montgomery to Whitehall, which is impossible, since the flow is from Whitehall toward Fort Montgomery.

### COOPERVILLE TO HOGANSBURG.

This line was run in connection with the topographic survey under the direction of Frank P. Davis, assistant engineer, with Buff & Berger

wye level, from bench mark 1, elevation 104.147, at Cooperville, via Champlain and Valleyfield to United States permanent bench mark P, on Catholic church at Hogansburg, making its elevation 180.392. But since the elevation used of bench mark 1 was 1.109 feet too high, we have 180.392 — 1.109 = 179.283 for the elevation of permanent bench mark P, at Hogansburg. These levels were begun in August, 1898, and completed in October, 1898.

HOGANSBURG TO CAPE VINCENT.

This is a duplicate line of precise levels run in the fall of 1898 and the spring of 1899 by D. A. Molitor, United States assistant engineer, using a Buff & Berger precise level. Starting at United States permanent bench mark P, at Hogansburg, elevation 179.283, and running along the St. Lawrence River to Cape Vincent, the zero of the gauge at that point was determined as 248.803. This gauge was read every ten minutes from 6 a. m. to 6 p. m. July 27 to August 6, 1898, and the mean of the readings for this time was 2.318 feet below the zero of the gauge. Therefore we have 248.803 — 2.318 = 246.485 for the elevation of the mean water surface in Lake Ontario at Cape Vincent July 27 to August 6, 1898, which is 0.114 foot lower than as determined for the same dates at Oswego via the Mohawk route.

*Notable elevations, in feet, above mean tide at New York.*

| Oswego-Mohawk route. | Feet. | Champlain route. | |
|---|---|---|---|
| Greenbush bench mark | 14.730 | Greenbush bench mark | 14.730 |
| Troy bench mark 1 | 22.084 | Troy bench mark 1 | 22.084 |
| Herkimer bench mark 75 | 389.408 | Whitehall bench mark 36 | 104.550 |
| Oswego bench mark A | 252.853 | Putnam station bench mark 39 | 107.615 |
| Oswego zero of gauge | 245.069 | Zero of Fort Montgomery gauge | 93.500 |
| Oswego mean water surface July 27 to August 6, 1898 | 246.599 | Rouse Point bench mark on Chapman Block | 108.951 |
| | | Cooperville bench mark 1 | 103.038 |
| | | Hogansburg permanent bench mark P. | 179.283 |
| | | Cape Vincent zero of gauge | 248.803 |
| | | Cape Vincent mean water surface July 27 to August 6, 1898 | 246.485 |

Assuming that the mean water surface in Lake Ontario was level from July 27 to August 6, 1898, we would then have 246.599 — 246.485 = 0.114 for the error of closure for the two lines of levels.

The lengths of the several lines, measured along the course actually traversed in this circuit, are as follows:

| | Miles. |
|---|---|
| Bench mark 1, at Troy, to Crown Point (wye levels) | 103.3 |
| Crown Point to Cooperville (water levels) | 64 |
| Cooperville to Hogansburg (wye levels) | 78.5 |
| Hogansburg to Cape Vincent (precise levels) | 118.3 |
| Cape Vincent to Oswego (water levels) | 47 |
| Oswego to Herkimer (wye levels) | 98.5 |
| Herkimer to bench mark 1, at Troy (wye levels) | 89.2 |
| Total | 598.8 |

| | Miles. |
|---|---|
| Total wye levels | 369.5 |
| Total precise levels | 118.3 |
| Total water levels | 111 |
| Total | 598.8 |

The distance, 7 miles, from bench mark 1, at Troy, to the Greenbush bench mark is common to both lines.

Respectfully submitted.

C. L. HARRISON,
*Principal Assistant Engineer.*

THE BOARD OF ENGINEERS ON DEEP WATERWAYS.

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## APPENDIX NO. 11.

### CHAMPLAIN ROUTE, ST. LAWRENCE DIVISION.

DETROIT, MICH., *September 30, 1899.*

GENTLEMEN: I respectfully submit herewith the following report on surveys of the St. Lawrence River from Ogdensburg to Lake St. Francis, and estimates of the cost of constructing a ship canal of 21 and 30 feet depth.

A field party was organized and reported for duty at Ogdensburg, N. Y., August 11, 1898. The base line and stadia field work were commenced on the 17th and soundings on the 22d. The boring party was equipped with a Sullivan boring machine for work on either land or water, and began work on the river September 1.

Topography was practically completed December 3, soundings December 14, and borings were discontinued December 20, 1898. Four land parties and one river party resumed borings April 11, 1899. The required field work was completed June 20, 1899. A small office force has been engaged on mapping, computations, and estimates up to September 20, 1899.

The field work was done in accordance with the general instructions to field parties, Appendix No. 9.

The field work has required an aggregate of 1,031 days' work by instrument men, recorders, and rodsmen, 681 days' work by stadia men and foremen, 276 days' work by teams with drivers, and 2,046 days' work by laborers. The office work has required 1,028 days' work by draftsmen and computers.

The principal items of topographical work were 39 miles of base line; 103.6 miles of stadia circuits; exclusive of side lines and such portions of base line as were included in the circuits; considerable work on levels which were dependent upon the bench marks established by Mr. David Molitor, United States assistant engineer, and which have not been reduced to miles run; about 20,900 soundings; 148 borings on land, aggregating 7,052 linear feet, of which 65 reached rock, and 151 borings on water, aggregating 2,123 linear feet, of which 94 reached rock.

Surveys were not carried over such portions of the river as were shown on existing charts to have a sufficient depth of navigable water. In Lake St. Francis estimates are based on data shown on existing charts and on soundings furnished by Mr. Tom S. Rubidge, superintending engineer of the St. Lawrence district, Cornwall, Ontario.

### HIGH AND LOW STAGES OF THE RIVER.

In order to determine the relations of fluctuations in the river with fluctuations in lake, and high and low water stages, a comparison of three points in the river is made with the three highest and three lowest stages of the lake at Oswego between the years 1865 and 1898. The points selected in the river are the head of the Galops Rapids at Lock No. 27, the head of Lake St. Francis at Lock No. 15, and the foot of Lake St. Francis at Lock No. 14. Gauge readings for Lock No. 27 during the year 1870 are not available; also gauge readings for Lock No. 15 are omitted during the first four months of the year on account of the effects of ice jams. The mean reading for the year and for the period of navigation, May to November, inclusive, are given.

TABLE No. 1.—*Tabulation of gauge readings for the three years.*

HIGHEST ANNUAL MEAN GAUGE READINGS SINCE 1865.

| | Oswego. | | | Lock No. 27. | | Lock No. 15. | | | Lock No. 14. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1870. | 1884. | 1886. | 1884. | 1886. | 1870. | 1884. | 1886. | 1870. | 1884. | 1886. |
| | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| January | 3.14 | 2.39 | 3.48 | 9.18 | 11.01 | ..... | ..... | ..... | 12.83 | 12.11 | 13.33 |
| February | 3.29 | 2.76 | 3.55 | 9.62 | 10.95 | ..... | ..... | ..... | 12.98 | 12.13 | 13.08 |
| March | 3.29 | 3.44 | 3.69 | 10.33 | 10.87 | ..... | ..... | ..... | 12.36 | 12.58 | 12.34 |
| April | 4.23 | 4.05 | 4.31 | 11.51 | 11.83 | ..... | ..... | ..... | 13.31 | 13.22 | 13.46 |
| May | 4.83 | 4.07 | 4.52 | 11.78 | 12.36 | 12.43 | 11.78 | 12.14 | 13.42 | 13.23 | 13.18 |
| June | 4.51 | 3.97 | 4.32 | 11.66 | 12.13 | 12.11 | 11.57 | 11.97 | 13.28 | 12.88 | 13.10 |
| July | 4.19 | 3.76 | 3.92 | 11.66 | 11.70 | 11.96 | 11.57 | 11.69 | 13.17 | 12.82 | 12.82 |
| August | 3.85 | 3.53 | 3.48 | 11.39 | 11.33 | 11.65 | 11.35 | 11.32 | 12.94 | 12.41 | 12.57 |
| September | 3.16 | 3.10 | 3.12 | 11.01 | 10.98 | 11.15 | 10.99 | 11.05 | 12.54 | 12.44 | 12.15 |
| October | 2.83 | 2.68 | 2.83 | 10.54 | 10.62 | 10.58 | 10.63 | 10.73 | 12.44 | 12.11 | 12.20 |
| November | 2.26 | 2.18 | 2.39 | 10.23 | 10.49 | 10.05 | 10.26 | 10.64 | 12.28 | 11.86 | 12.12 |
| December | 2.01 | 2.03 | 2.30 | 10.00 | 10.20 | 11.01 | 11.65 | 11.49 | 12.19 | 11.98 | 12.38 |
| Mean readings | 3.47 | 3.16 | 3.49 | 10.74 | 11.21 | ..... | ..... | ..... | 12.81 | 12.48 | 12.73 |
| Mean readings, May-November | 3.66 | 3.33 | 3.51 | 11.18 | 11.37 | 11.42 | 11.16 | 11.36 | 12.87 | 12.54 | 12.59 |

LOWEST ANNUAL MEAN GAUGE READINGS SINCE 1865.

| | Oswego. | | | Lock No. 27. | | | Lock No. 15. | | | Lock No. 14. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1895. | 1896. | 1897. | 1895. | 1896. | 1897. | 1895. | 1896. | 1897. | 1895. | 1896. | 1897. |
| | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| January | .37 | —.32 | —.24 | 8.02 | 7.65 | 7.78 | ..... | ..... | ..... | 11.50 | 11.21 | 10.47 |
| February | .31 | +.20 | —.30 | 7.19 | 7.80 | 7.61 | ..... | ..... | ..... | 10.57 | 11.18 | 10.35 |
| March | .21 | .37 | +.20 | 7.46 | 7.70 | 8.11 | ..... | ..... | ..... | 10.68 | 10.69 | 10.78 |
| April | .76 | 1.30 | .84 | 8.50 | 8.93 | 8.94 | ..... | ..... | ..... | 11.95 | 11.96 | 11.58 |
| May | .88 | 1.31 | 1.28 | 8.83 | 9.32 | 9.21 | 9.66 | 9.83 | 9.89 | 11.46 | 11.88 | 11.63 |
| June | .76 | 1.22 | 1.50 | 8.67 | 9.14 | 9.58 | 9.53 | 9.73 | 9.92 | 11.28 | 11.44 | 11.65 |
| July | .47 | .96 | 1.49 | 8.37 | 9.03 | 9.50 | 9.23 | 9.56 | 9.91 | 10.96 | 11.25 | 11.52 |
| August | +.22 | .82 | 1.48 | 8.20 | 8.88 | 9.48 | 9.17 | 9.43 | 9.90 | 10.98 | 11.12 | 11.38 |
| September | —.12 | .34 | .98 | 7.98 | 8.40 | 8.93 | 8.80 | 9.06 | 9.38 | 10.54 | 10.77 | 11.09 |
| October | —.46 | +.11 | .35 | 7.63 | 8.19 | 8.43 | 8.54 | 8.78 | 8.94 | 10.39 | 10.44 | 10.68 |
| November | —.71 | —.15 | .29 | 7.42 | 8.08 | 8.16 | 8.37 | 8.77 | 8.88 | 10.17 | 10.44 | 10.68 |
| December | —.68 | —.15 | .35 | 7.45 | 7.91 | 8.23 | 8.83 | 9.32 | 9.17 | 10.47 | 10.51 | 10.96 |
| Mean readings | .17 | .50 | .68 | 7.98 | 8.42 | 8.66 | ..... | ..... | ..... | 10.91 | 11.07 | 11.06 |
| Mean readings, May-November | .15 | .66 | 1.05 | 8.16 | 8.72 | 9.04 | 9.04 | 9.31 | 9.54 | 10.83 | 11.05 | 11.23 |

Taking the difference between the highest and lowest mean monthly readings gives a fluctuation of Lake Ontario at Oswego of 5.54 feet. The months taken are May, 1870, 4.83 feet, and November, 1895, —0.71. The fluctuation in the St. Lawrence River at lock No. 27, between the months of May, 1886, and November, 1895, is 4.94 feet. At locks Nos. 15 and 14 the difference between the mean readings of May, 1870, and November, 1895, gives a fluctuation of 4.06 and 3.25 feet, respectively.

The year 1870 gives a slightly lower annual mean reading than that for 1886, but a higher mean for the period of navigation. The curves of gauge readings for these years are nearly similar. More data are available for the year 1886, and it is taken as a typical high-water stage for detailed comparison with the low-water stage of 1895.

The general location and approximate stations of the Canadian gauges used in the St. Lawrence River are as follows:

| General location of Canadian gauges. | No. | Station. |
|---|---|---|
| Near the head of Galops Island, Galops Canal | 27 | 3620 |
| Opposite Point Rockway at Iroquois, Galops Canal | 25 | 4055 |
| Near the head of Ogdens Island, Rapide Plat Canal | 24 | 4260 |
| Opposite Dry Island at Morrisburg, Rapide Plat Canal | 23 | 4470 |
| Near the head of Croills Island, Farrans Plat Canal | 22 | 5010 |
| Opposite central part of Long Sault Island, Cornwall Canal | 21 | 5280 |
| Opposite Cornwall Island at Cornwall, Cornwall Canal | 15 | 5795 |
| Near the foot of Lake St. Francis, Beauharnois Canal | 14 | ..... |

The above stations indicate the approximate location of the gauges, but the elevation of the water surface at the gauge does not correspond exactly to the elevation of water surface at the proposed center-line station, on account of its distance from the center line, intervening islands, eddies, etc.

TABLE NO. 2.—*Comparison of the high-water stage of 1886 and the low-water stage of 1895 of Lake Ontario with the St. Lawrence River through Lake St. Francis.*

| Location of gauges. | Year. | Average monthly readings. | | | | | | | Mean reading, May to November, inclusive. |
|---|---|---|---|---|---|---|---|---|---|
| | | May. | June. | July. | August. | September. | October. | November. | |
| | | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| Lake Ontario at Oswego, N. Y. | 1886 | 4.52 | 4.32 | 3.92 | 3.48 | 3.12 | 2.83 | 2.39 | 3.51 |
| | 1895 | 0.88 | 0.76 | 0.47 | +0.22 | —0.12 | —0.46 | —0.71 | +0.15 |
| St. Lawrence River at lock No. 27 | 1886 | 12.36 | 12.13 | 11.70 | 11.33 | 10.98 | 10.62 | 10.49 | 11.37 |
| | 1895 | 8.83 | 8.67 | 8.37 | 8.20 | 7.98 | 7.63 | 7.42 | 8.16 |
| Lock No. 25 | 1886 | 14.70 | 14.72 | 14.07 | 13.69 | 13.29 | 12.58 | 12.57 | 13.66 |
| | 1895 | 10.31 | 10.26 | 9.66 | 9.40 | 8.81 | 8.34 | 7.81 | 9.23 |
| Lock No. 24 | 1886 | 11.83 | 11.67 | 11.17 | 10.67 | 10.42 | 10.08 | 9.83 | 10.81 |
| | 1895 | 7.83 | 7.67 | 7.42 | 7.08 | 6.50 | 6.17 | 5.67 | 6.90 |
| Lock No. 23 | 1886 | 11.92 | 11.67 | 11.33 | 10.75 | 10.42 | 10.00 | 9.75 | 10.83 |
| | 1895 | 7.75 | 7.58 | 7.17 | 7.00 | 6.42 | 6.00 | 5.58 | 6.79 |
| Lock No. 22 | 1886 | 11.59 | 11.49 | 11.12 | 10.67 | 10.41 | 10.08 | 9.82 | 10.74 |
| | 1895 | 8.47 | 8.37 | 8.08 | 7.89 | 7.52 | 7.17 | 6.70 | 7.74 |
| Lock No. 21 | 1886 | 12.17 | 12.00 | 11.67 | 11.33 | 11.00 | 10.67 | 10.50 | 11.33 |
| | 1895 | 9.00 | 8.92 | 8.67 | 8.58 | 8.25 | 7.92 | 7.67 | 8.43 |
| Lock No. 15 | 1886 | 12.14 | 11.97 | 11.69 | 11.32 | 11.05 | 10.73 | 10.64 | 11.36 |
| | 1895 | 9.66 | 9.52 | 9.22 | 9.17 | 8.80 | 8.54 | 8.37 | 9.04 |
| Lock No. 14 | 1886 | 13.18 | 13.10 | 12.82 | 12.57 | 12.15 | 12.20 | 12.12 | 12.59 |
| | 1895 | 11.46 | 11.28 | 10.96 | 10.98 | 10.54 | 10.39 | 10.17 | 10.83 |

In Table No. 3 the difference between the mean gauge readings for May to November, inclusive, for 1886 and 1895 are reduced to a percentage of the fluctations in Lake Ontario.

Differences between the standard high water determined in the 1896 report of the United States Deep Waterways Commission and the high stage of May, 1886, is given; also the differences between standard low water and the mean low stage during the period of navigation for 1895.

The difference between the high stage of May, 1886, and the low stage of May to November, inclusive, for 1895 is given.

The difference between standard low water and that period covered by simultaneous gauge readings by Mr. David Molitor, United States assistant engineer, is also shown.

TABLE No. 3.—*Tabulation of various gauge readings and differences.*

| | Lake Ontario at Oswego. | St. Lawrence River at Canadian locks. | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | No. 27. | No. 25. | No. 24. | No. 23. | No. 22. | No. 21. | No. 15. | No. 14. |
| Mean gauge readings, May–November: | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* | *Feet.* |
| 1886 | 3.51 | 11.37 | 13.66 | 10.81 | 10.83 | 10.74 | 11.33 | 11.36 | 12.59 |
| 1895 | 0.15 | 8.16 | 9.23 | 6.90 | 6.79 | 7.74 | 8.43 | 9.04 | 10.83 |
| Differences | 3.36 | 3.21 | 4.43 | 3.91 | 4.04 | 3.00 | 2.90 | 2.32 | 1.76 |
| Percentage of differences | 100 | 96 | 132 | 116 | 120 | 89 | 86 | 69 | 52 |
| Standard high water of 1896 report | 4.83 | 12.67 | 15.67 | ..... | 12.58 | 10.83 | ..... | 12.42 | 13.42 |
| Mean monthly readings for May, 1886 | 4.52 | 12.36 | 14.70 | 11.83 | 11.92 | 11.59 | 12.17 | 12.14 | 13.18 |
| Differences | 0.31 | 0.31 | 0.97 | ..... | 0.66 | −0.76 | ..... | 0.28 | 0.24 |
| Standard low water of 1896 report | 0.32 | 8.31 | 9.49 | (7.18) | 6.99 | 7.95 | (8.60) | 9.13 | 10.98 |
| Less mean readings of May–November, 1895 | 0.17 | 0.15 | 0.26 | 0.28 | 0.20 | 0.21 | 0.17 | 0.09 | 0.15 |
| Mean of May, 1886, less the mean of May to November, inclusive, 1895 | 4.37 | 4.20 | 5.47 | 4.93 | 5.13 | 3.85 | 3.74 | 3.10 | 2.35 |
| Mean gauge readings, July 27–August 6, 1898 | 1.53 | 9.19 | 10.89 | 8.50 | 8.39 | 8.85 | 9.49 | 9.80 | 11.34 |
| Less standard low water of 1896 report | 1.21 | 0.88 | 1.40 | 1.32 | 1.40 | 0.90 | 0.89 | 0.67 | 0.36 |

In Appendix No. 1, page 128, of the "Annual report of the department of railways and canals," Dominion of Canada, for the fiscal year from July 1, 1890, to June 30, 1891, is a "Statement of the highest and lowest water on the canals in the St. Lawrence district, May to November in each year," from 1849 to 1891, for gauges at locks Nos. 15, 21, 23, 24, 25, and 27. A similar statement in the report for the fiscal year from July 1, 1896, to June 30, 1897, on page 161, Part I, continues this data to June, 1897.

The following readings show the highest daily readings occurring during those months when water stood at or more than 0.5 foot above the mean reading of May, 1886, for the corresponding gauge:

*Highest gauge reading.*

Lock No. 27, May, 1870 ..... 13.00

Lock No. 25:

July, 1867 ..... 15.67

May, 1870 ..... 16.17

July, 1876 ..... 15.67

May, 1884 ..... 15.83

May, 1886 ..... 15.25

| | |
|---|---|
| Lock No. 24: | |
| July, 1867 | 12.50 |
| May, 1870 | 13.00 |
| May, 1876 | 12.75 |
| May, 1884 | 12.50 |
| Lock No. 23: | |
| June, 1867 | 12.83 |
| May, 1870 | 12.75 |
| July, 1876 | 12.50 |
| May, 1884 | 12.75 |
| Lock No. 22, July, 1876 | 12.50 |
| Lock No. 21: | |
| May, 1870 | 12.75 |
| June, 1886 | 12.92 |
| Lock No. 15, June, 1870 | 12.67 |

These maximum daily readings average approximately 1 foot above the mean high stage of May, 1886.

The following readings show the lowest daily readings occurring during those months when the water stood at or lower than 0.5 foot below the mean readings of 1895, May to November, inclusive:

| | *Lowest gauge reading.* |
|---|---|
| Lock No. 27: | |
| November, 1889 | 7.08 |
| November, 1895 | 6.75 |
| November, 1896 | 7.50 |
| Lock No. 25: | |
| November, 1875 | 8.33 |
| November, 1887 | 8.33 |
| October, 1891 | 7.83 |
| November, 1895 | 6.67 |
| November, 1896 | 8.25 |
| Lock No. 24: | |
| November, 1875 | 6.25 |
| November, 1889 | 6.00 |
| November, 1895 | 4.42 |
| November, 1896 | 5.58 |
| Lock No. 23: | |
| November, 1875 | 6.00 |
| November, 1895 | 4.83 |
| November, 1896 | 5.75 |
| Lock No. 22: | |
| November, 1895 | 5.83 |
| November, 1896 | 6.92 |
| Lock No. 21: | |
| November, 1895 | 7.33 |
| November, 1896 | 7.67 |
| Lock No. 15: | |
| November, 1895 | 8.00 |
| November, 1896 | 8.54 |

Table No. 4 shows the approximate location of the gauges established by Mr. David Molitor, United States assistant engineer, over

that stretch of the river under consideration, and the reduction of the mean elevations of the water surface to standard low water.

The percentage corrections are determined by multiplying 1.21, which is that stage of Lake Ontario at Oswego during the period covered by the simultaneous gauge readings, by a factor obtained from the percentages of fluctuations found between the mean high water, 1886, and the mean low water of 1895, at the various Canadian gauges during the period of navigation. The approximate elevation of standard low water so determined is used for a comparison with the reductions otherwise obtained.

All elevations used in this report are based on a line of levels run under direction of the United States Board of Engineers on Deep Waterways from the Greenbush bench mark elevation, 14.73 feet above mean tide at New York.

TABLE No. 4.

| No. | General location. | Station. | Mean elevation water surface. | Percentage correction. | Elevation standard low water. |
|---|---|---|---|---|---|
| 15 | Ogdensburg | 3272 | 245.811 | 1.16 | 244.65 |
| 14 | Butternut Island | 3586 | 244.868 | 1.16 | 243.71 |
| 13 | Sheldon Island | 3811 | 235.805 | 1.22 | 234.59 |
| 12 | Point Rockway | 4070± | 228.543 | 1.60 | 226.94 |
| 11 | Leishmans Point | 4225± | 226.412 | 1.42 | 224.99 |
| 10 | Waddington, below dam | 4346 | 215.202 | 1.42 | 213.78 |
| 9 | Murphys Island | 4510± | 213.675 | 1.45 | 212.23 |
| 8 | Above Bradfords Hill | 4735± | 208.983 | 1.32 | 207.66 |
| 7 | Below Bradfords Hill | 4770± | 207.657 | 1.26 | 206.40 |
| 6 | Louisville Landing | 4975 | 206.188 | 1.09 | 205.10 |
| 5 | Richards Landing | 5123 | 204.792 | 1.05 | 203.74 |
| 2 | Grass River | 5633 | 156.844 | 0.91 | 155.93 |
| 1 | Racket River | 5855 | 154.595 | 0.82 | 153.78 |

Table No. 5, giving the standard high and low water after completion of proposed work, has been computed from the elevation of the actual water surface, taken on various dates, reduced to standard low water by a comparison with the Oswego gauge readings for the corresponding dates, reduced to standard low water at the desired point by applying the percentage correction shown in Table No. 3, by a comparison with the standard low water obtained by applying the same percentage to the mean elevations determined by Mr. David Molitor, United States assistant engineer, and by a comparison with the difference between the nearest Canadian gauge reading and its standard low water. The various results thus obtained practically agree.

The standard high water, after completion of the proposed works, is determined by a comparison of the high stage of Lake Ontario at Oswego, reduced to an elevation at the desired point by applying the percentage correction, and by a comparison with standard high water of the nearest Canadian gauges. The results thus obtained agree within reasonable limits.

The grade used for the channels of 30 or 21 feet depth, on which estimates depend, are determined by subtracting 30 or 21 feet from the standard low water, except as is noted under details of the estimates of the respective channels.

TABLE No. 5.

| General location. | Station. | Number of nearest gauge. | | Elevation. | |
|---|---|---|---|---|---|
| | | Molitor's. | Canadian. | Standard high water.[1] | Standard low water.[1] |
| State hospital grounds | 3449 | 14 | 27 | 248.8 | 244.4 |
| Head of Galops Island | 3629 | 14 | 27 | 247.1 | 242.7 |
| Lock, Sheldon Island | 3779 | 13 | 27 | 247.1 | 242.7 |
| Do | 3779 | 13 | 27 | 237.5 | 233.0 |
| Leishmans Point | 4213 | 11 | 24 | 231.0 | 225.7 |
| Lock, Clarks Point | 4372 | 10 | 23 | 231.0 | 225.7 |
| Do | 4372 | 10 | 23 | 219.4 | 213.9 |
| Off Dry Island | 4465 | 9 | 23 | 218.4 | 212.8 |
| Below Bradfords Hill | 4765 | 7 | 22 | 210.9 | 206.2 |
| Off Chat Island | 4925 | 6 | 22 | 209.3 | 205.2 |
| Richards Point | 5075 | 6 | 22 | 209.0 | 205.0 |
| St. Lawrence Power Company Canal | 5233 | | | 208.5 | 204.5 |
| Lock, Massena Valley | 5508 | | | 208.5 | 204.5 |
| Do | 5508 | | | 160.2 | 156.8 |
| Near the mouth of Grass River | 5633 | 2 | 15 | 160.2 | 156.8 |
| Off Cornwall Island | 5815 | 1 | 15 | 157.0 | 153.7 |
| Off St. Regis Island | 6035 | 1 | 15 | 156.7 | 153.4 |
| Lower portion Lake St. Francis | 7280 | 1 | 15 | 155.5 | 153.0 |

[1] After improvement has been completed.

Stations showing location of head of locks as given in Table No. 5 are for the 30-foot channel. The location of the locks for the 21-foot channel does not correspond exactly with the locks of the 30-foot channel.

EFFECT OF ICE JAMS.

Ice jams in the vicinity of St. Regis Island occur during the winter months, occasionally beginning in December or extending into April. The rise of water is generally from 10 to 20 feet above standard low water.

The following readings show the highest readings during the months indicated, wherein the gauge readings of the Cornwall Lock No. 15 were over 30 feet, or 21 feet above standard low water, between the years 1862 to 1899, inclusive:

| Date. | Reading. | Height above standard low water. |
|---|---|---|
| February, 1870 | 31.42 | 22.29 |
| January, 1871 | 30.42 | 21.29 |
| January, 1884 | 32.17 | 23.04 |
| January, 1885 | 30.67 | 21.54 |
| January, 1887 | 38.33 | 29.20 |
| March, 1891 | 30.25 | 21.12 |

Effects produced by ice jams in the vicinity of proposed construction between Ogdensburg and the entrance to the land canal at Richards Point can be disregarded.

## GENERAL TOPOGRAPHY AND MATERIAL ENCOUNTERED.

From Ogdensburg to Waddington the ridge adjacent to the river is wide and varies from 40 to 70 or more feet above the water surface. It is broken by a few small creeks. In the vicinity of Gooseneck Island and Louisville Landing valleys extend southward toward the Grass River, which, at the latter place, approaches within about 3 miles of the St. Lawrence. From this point the trend of the ridges or valleys is nearly parallel to the St. Lawrence for a distance of about 11 miles, to the mouth of the Grass River. Several cross-overs exist between the valleys.

The higher portions of points and islands crossed by the proposed center line have a rich but shallow loamy surface. The Massena valleys are in general fertile bottom lands.

The usual formation of all points, islands, and ridges is a core of bowlder clay approaching close to the surface on the upstream side, while on the downstream side considerable clay and sand of softer material is frequently found. A portion of the bowlder clay is more or less cemented and is classified as "hardpan" in the detailed estimates of yardage and cost. The remaining portion is classified as "hard material." It consists of sand, gravel, and bowlders in varying proportions, mixed with clay, but not cemented. Hardpan is imposed upon several feet of soft blue clay in a few cases.

The bulk of the clay is soft blue clay; a small proportion is a tough yellow clay. All the gravel found is angular, and appears to have been formed from local rock. It generally contains a small amount of clay, but not enough to cement it together.

The rock appears to be a heavy dark-gray limestone with a clear ring and good weathering properties, as is shown by various outeroppings in the vicinity of Lisbon, Waddington, and Hogansburg. It is called a calciferous sandstone; the percentage of lime varies through a large range. Rock excavation was in progress on the St. Lawrence Power Company's canal and on the Canadian Canal improvements. It was easily drilled and conveniently broken for loading into cars, skips, etc. The strata are practically horizontal, and vary in thickness from a few inches up to about 5 feet.

Some public buildings and dwellings are constructed from stone taken from local quarries. A similar stone is used in the construction of a portion of the masonry in the Canadian locks.

A considerable area of rock outeroppings appears on river bottoms at the Galops Rapids and the Rapide Plat. Other river bottoms in the vicinity of swift water are thickly covered with medium-sized bowlders.

## GENERAL ROUTE AND ESTIMATES.

Those stretches of the river requiring radical improvement are the Galops Rapids, the swift water in the vicinity of Long Point and Point

Rockway, the Rapide Plat, and the swift water extending from Croïlls Island to Cornwall Island, including the Long Sault.

Estimates are based upon the standard sections and designs, except that the 600-foot river channel has been contracted to a 400-foot width between Lalone Island and the mainland, channel limits being above high water. In a few other places, where a side slope would extend into a high shore, a contraction of 100 feet on that side has been made. Additional excavation in river sections has been estimated at all curves between the outer curve and its tangents.

No slope walls are estimated adjacent to river sections, where the excavated shore is hard material, as is the case at Lalone Island, Long Point, Point Rockway, and a few other places.

For convenience in tabulating quantities and cost the proposed work is divided into sections, as follows:

*Section 1.*—Station 3481 to station 3763; from the St. Lawrence State hospital grounds to the dock at entrance of the Sheldon Island lock.

*Section 2.*—Station 3763 to station 3819; Sheldon Island lock and excavation out to deep water.

*Section 3.*—Station 3819 to station 3885; general river improvements at Long Point.

*Section 4.*—Station 3999 to station 4066; general river improvements at Point Rockway.

*Section 5.*—Station 4206 to station 4233; Leishmans Point.

*Section 6.*—Station 4233 to station 4261; Leishmans Point to land canal in Ogdens Island.

*Section 7.*—Station 4261 to station 4278; land canal in Ogdens Island.

*Section 8.*—Station 4278 to station 4356; from Ogdens Island canal to dock at entrance of lock in Clarks Point.

*Section 9.*—Station 4356 to station 4396; lock at Clarks Point.

*Section 10.*—Station 4396 to station 4933; from the end of dock below Clarks Point to deep water beyond Chat Island.

*Section 11.*—Station 5055 to station 5491; from Richards Point to the dock for the Massena Valley lock.

*Section 12.*—Station 5491 to station 5532; the Massena Valley lock.

*Section 13.*—Station 5532 to station 5635; from the Massena Valley lock to the deep water in the St. Lawrence River near the mouth of Grass River.

*Section 14.*—Station 5668 to station 7028; from below the mouth of Grass River to opposite McKees Point, Lake St. Francis.

The estimates for the proposed river improvements for the North Galops channel and for Long Point and Point Rockway are the same for the canals of 30 or 21 feet depth.

DETAILED ESTIMATES, 30-FOOT CHANNEL.

Estimates are based on slack-water navigation from the head of Galops Island to the foot of Sheldon Island by means of rock-filled dams, connecting Galops, Benedict, Raycraft, Lalone, and Sheldon islands, and Sheldon Island with the mainland opposite, the lock of 9.7 feet lift, standard low water, being located in Sheldon Island.

It is proposed to enlarge the North Galops channel by excavating a 20-foot channel 1,300 feet wide through the adjacent portions of Galops and Adams islands. The present channel at this point is estimated at 5,000 square feet area. The proposed channel would be 26,000 square feet, giving an increased area of 21,000 square feet. The present area of the North Channel between Adams Island and the guard wall of the Canadian canal is 16,000 square feet. The area of the South Channel near Red Mill Point is 19,500 square feet. This improvement of the North Channel, with the slack-water navigation in the South Channel, would make the cross section available for discharge to the Galops Rapids practically unchanged. The yardage and classification of material has been determined from the data on existing charts, and the estimated cost of the same is regarded as equivalent to the cost of any required improvements at this point.

The yardage of material required for rock-filled dams is based upon a dam 4 feet above high water, having a top width of 20 feet and side slopes of 1½ to 1. No deduction is made in these quantities for the material that could be deposited by scows, etc., from the "excavation under water." The river bottom at the dam sites is either rock or hard material. The present currents between the islands have a maximum surface velocity of from 3 to 4 miles per hour, and are directed northward, except between Lalone and Sheldon islands.

In general, the bulk of the material necessary for dams, back filling, embankments, and crushed stone for concrete is available from the material to be excavated from channel.

TABLE NO. 6.

ESTIMATE, 30-FOOT CHANNEL.

*Section 1.*—The estimated yardage and cost of material to be excavated and dams constructed are as follows:

| | |
|---|---|
| Excavation under water: | |
| Rock, 2,939,642 cubic yards, at $2.50 | $7,349,105 |
| Hard material, 1,098,583 cubic yards, at 25 cents | 274,646 |
| Gravel, 106,050 cubic yards, at 15 cents | 15,908 |
| Excavation in the dry: | |
| Rock, 25,036 cubic yards, at 65 cents | 16,273 |
| Hard material, 103,018 cubic yards, at 25 cents | 25,755 |
| Gravel, 41,112 cubic yards, at 15 cents | 6,167 |

For the improvement of the North Galops Channel:

| | |
|---|---|
| Excavation under water: | |
| Rock, 566,908 cubic yards, at $2.50 | $1,417,270 |
| Hard material, 226,805 cubic yards, at 25 cents | 56,701 |
| Excavation in the dry: | |
| Rock, 592,444 cubic yards, at 65 cents | 385,089 |
| Hard material, 860,389 cubic yards, at 25 cents | 215,097 |
| Rock-filled dams: | |
| Between Galops and Benedict islands, 20,737 cubic yards, at 50 cents | 10,368 |
| Between Benedict and Raycraft islands, 21,972 cubic yards, at 50 cents | 10,986 |
| Between Raycraft and Lalone islands, 46,425 cubic yards, at 50 cents | 23,212 |
| Between Lalone and Sheldon islands, 30,310 cubic yards, at 50 cents | 15,155 |
| Right of way: | |
| On Galops Island, including the acreage required for river improvements at the northwest portion, 114 acres, at $75 | 8,550 |
| On mainland opposite Galops Island, 10 acres, at $75 | 750 |
| Six islands, including Adams Island | 6,500 |
| Total estimated cost of section 1 | 9,837,532 |

*Section 2.*—Docks and cribs in approaches to the lock, the lock, and the retaining-wall quantities are based on the standard designs.

The lock is located between station 3777+29 and station 3787+00 in Sheldon Island. The lift at standard low water is 9.7 feet. The fluctuation of high water is 4.4 feet and 4.5 feet. Both above and below the lock, respectively, the foundations are on rock.

The estimated quantities and cost of construction are as follows:

| | |
|---|---|
| Excavation under water: | |
| Rock, 33,459 cubic yards, at $2.50 | $83,647 |
| Hardpan, 112,788 cubic yards, at $1 | 112,788 |
| Hard material, 311,926 cubic yards, at 25 cents | 77,981 |
| Clay, 89,643 cubic yards, at 15 cents | 13,446 |
| Gravel, 6,144 cubic yards, at 15 cents | 922 |
| Excavation in the dry: | |
| Rock, 267,850 cubic yards, at 65 cents | 174,103 |
| Hardpan, 106,492 cubic yards, at 35 cents | 37,272 |
| Hard material, 85,993 cubic yards, at 25 cents | 21,498 |
| Clay, 48,911 cubic yards, at 15 cents | 7,337 |
| Approaches to lock (docks): | |
| Timber— | |
| Oak, 79,680 feet B. M., at $50 per M | 3,984 |
| Hemlock, 5,588,962 feet B. M., at $23 per M | 128,546 |
| Pine, 1,594,432 feet B. M., at $30 per M | 47,832 |
| Stone fill, 88,441 cubic yards, at 60 cents | 53,065 |
| Iron, driftbolts, 652,005 pounds, at 3 cents | 19,560 |
| Retaining walls, 4,849 cubic yards, at $4 | 19,396 |
| Rock-filled dam from Sheldon Island to mainland, 50,046 cubic yards, at 50 cents | 25,023 |
| Back fill, 105,128 cubic yards, at 25 cents | 26,282 |

| | | |
|---|---|---|
| Lock No. 1 (Sheldon Island) | | $816,888 |
| Lock operating machinery | | 100,000 |
| Right of way: | | |
| Sheldon Island, 62 acres, at $100 | $6,200 | |
| Mainland, 20 acres, at $75 | 1,500 | |
| | | 7,700 |
| Total estimated cost of section 2 | | 1,777,270 |

*Sections 3 and 4.*—It is proposed to improve the river at Long Point and at Point Rockway by so increasing the cross section that the slope shall be practically uniform from Sheldon Island to Leishmans Point.

Simultaneous gauge readings taken above and below Long Point give a difference in elevation of water surface of 2.25 feet in a distance of 4,000 feet, estimated along the central thread of the river. The present estimated mean available area at an elevation of 234 feet, corresponding to that stage of the river during which discharge measurements were made at Ogdensburg, is 37,540 square feet. This gives, with the measured discharge of 219,100 cubic feet per second, a mean velocity of 5.84 feet per second. The maximum velocity observed by using rod floats submerged about 6 feet was 10.3 feet per second.

The proposed river improvements upon which estimates are based increase the area to 56,860 square feet and decrease the mean velocity to 3.9 feet per second.

Similarly, at Point Rockway, a difference in elevation of 3.70 feet in an estimated distance of 7,000 feet was determined. The elevation of water surface for the mean present section of 33,150 square feet for a stage corresponding to that used for Long Point is 229.6 feet. The mean velocity is 6.6 feet per second. The maximum observed velocity was 9.8 feet per second.

The area at this point is increased to 51,730 square feet and the mean velocity reduced to 4.2 feet per second.

Eddies exist below both Long Point and Point Rockway, and the estimated distances of 4,000 feet and 7,000 feet, respectively, may be too small for representing present conditions. The proposed improvements would destroy or largely decrease these eddies.

These increased areas at Point Rockway and Long Point will decrease the elevation of the water surface below Sheldon Island about 1.6 feet. The increased area at the head of the North Galops Channel will tend to decrease this effect. The decrease of the velocity of approach to the pools below Long Point and Point Rockway will tend toward a relative increase in the elevation of the water surface at the head of these pools. The resulting slopes at the improved points and through the pools are nearly the same. Therefore a uniform slope for estimating the yardage of excavation is used from the lock approaches below Sheldon Island to Leishmans Point.

The estimate is based on excavating all material from a side line 100 feet to right of the center line, slopes 2 on 1, out to deep water, and the quantities are the same for the proposed canals of either 21 or 30 feet depth.

The estimated quantities and cost are as follows:

| | |
|---|---|
| Section 3: | |
| Excavation under water— | |
| Hardpan, 818,948 cubic yards, at $1 | $818,948 |
| Clay, 7,160 cubic yards, at 15 cents | 1,074 |
| Excavation in the dry— | |
| Hardpan, 680,631 cubic yards, at 35 cents | 238,221 |
| Clay, 277,110 cubic yards, at 15 cents | 41,567 |
| Right of way, 36 acres, at $75 | 2,700 |
| Total estimated cost of section 3 | 1,102,510 |
| Section 4: | |
| Excavation under water— | |
| Rock, 61,348 cubic yards, at $2.50 | 153,370 |
| Hard material, 1,101,611 cubic yards, at 25 cents | 275,403 |
| Excavation in the dry— | |
| Rock, 105,317 cubic yards, at 65 cents | 68,456 |
| Hard material, 595,036 cubic yards, at 25 cents | 148,759 |
| Right of way, 37 acres, at $75 | 2,775 |
| Total estimated cost of section 4 | 648,763 |

At the Rapide Plat it is proposed to obtain slack-water navigation by a rock-filled dam between Clarks Point and Ogdens Island and a lock located in Clarks Point. A land canal, earth section, will be necessary through Leishmans Point and through a portion of Ogdens Island. Otherwise the 600-foot river section through the Little River is used in estimating quantities to be excavated. The maximum velocity observed just below the entrance to the land canal at Leishmans Point was 8 feet per second, about 700 feet off the shore—a velocity greater than that existing on the proposed sailing course at and above this entrance. A guard crib 300 feet long, of the standard section, is estimated for at this point.

This proposition would destroy the existing dam and water power at Waddington. It is estimated that 15,000 theoretical horsepower could be developed by properly improving the dam and the highway crossing above the same and the canal. Three mills, including the electric-lighting plant, are located on the dam, which is 950 feet long, and eight mills are located on the canal, which is 950 feet long. These mills consist of two flour and grist mills, a lighting plant, milk receiver, blacksmith shop, planing, shingle, and saw mills, etc. Their outputs are mainly to meet local demands. The total present capacity of the above mills will not exceed 300 horsepower. The valuation of this property is based upon its possible future improvement.

The lock at Clarks Point is on rock foundation; the lift at standard low-water is 11.8 feet; the high water above the lock is 5.3 feet, and below the lock it is 5.5 feet above standard low water.

The division of excavation under water and in the dry has been determined from the present shore line.

The estimated quantities and cost for sections 5 to 9, inclusive, are tabulated as follows:

| | |
|---|---|
| Section 5: | |
| Excavation under water— | |
| Rock, 23,626 cubic yards, at $2.50 | $59,065 |
| Hard material, 46,245 cubic yards, at 25 cents | 11,561 |
| Clay, 52,860 cubic yards, at 15 cents | 7,929 |
| Gravel, 28,275 cubic yards, at 15 cents | 4,241 |
| Excavation in the dry— | |
| Rock, 104,195 cubic yards, at 65 cents | 67,727 |
| Hard material, 638,665 cubic yards, at 25 cents | 159,666 |
| Clay, 75,560 cubic yards, at 15 cents | 11,334 |
| Guard crib at entrance— | |
| Timber— | |
| Hemlock, 538,620 feet B. M., at $23 per M | 12,388 |
| Pine, 163,536 feet B. M., at $30 per M | 4,906 |
| Stone fill, 8,400 cubic yards, at 60 cents | 5,040 |
| Iron driftbolts, 62,585 pounds, at 3 cents | 1,878 |
| Slope walls, 8,125 square yards, at $1.10 | 8,937 |
| Right of way, 47 acres, at $75 | 3,525 |
| Total estimated cost of section 5 | 358,197 |
| Section 6: | |
| Excavation under water— | |
| Rock, 340,557 cubic yards, at $2.50 | 851,393 |
| Hard material, 497,450 cubic yards, at 25 cents | 124,362 |
| Clay, 90,350 cubic yards, at 15 cents | 13,552 |
| Gravel, 12,868 cubic yards, at 15 cents | 1,930 |
| Total estimated cost of section 6 | 991,237 |
| Section 7: | |
| Excavation in the dry— | |
| Rock, 61,129 cubic yards, at 65 cents | 39,734 |
| Hard material, 217,969 cubic yards, at 25 cents | 54,492 |
| Clay, 3,404 cubic yards, at 15 cents | 511 |
| Gravel, 595,707 cubic yards, at 15 cents | 89,356 |
| Slope walls, 11,500 square yards, at $1.10 | 12,650 |
| Right of way, 76 acres, at $75 | 5,700 |
| Total estimated cost of section 7 | 202,443 |
| Section 8: | |
| Excavation under water— | |
| Rock, 1,396,943 cubic yards, at $2.50 | 3,492,357 |
| Hard material, 301,827 cubic yards, at 25 cents | 75,457 |
| Clay, 715,477 cubic yards, at 15 cents | 107,322 |
| Gravel, 236,336 cubic yards, at 15 cents | 35,450 |

| | |
|---|---|
| Section 8—Continued. | |
| Excavation in the dry— | |
| Rock, 113,883 cubic yards, at 65 cents | $74,024 |
| Hard material, 106,736 cubic yards, at 25 cents | 26,684 |
| Gravel, 80,808 cubic yards, at 15 cents | 12,121 |
| Right of way, 20 acres, at $75 | 1,500 |
| Water power and mill properties | 100,000 |
| Total estimated cost of section 8 | 3,924,915 |
| Section 9: | |
| Excavation under water— | |
| Rock, 12,230 cubic yards, at $2.50 | 30,575 |
| Hard material, 144,100 cubic yards, at 25 cents | 36,025 |
| Clay, 172,069 cubic yards, at 15 cents | 25,810 |
| Excavation in the dry— | |
| Rock, 129,515 cubic yards, at 65 cents | 84,185 |
| Hardpan, 221,494 cubic yards, at 35 cents | 77,523 |
| Hard material, 34,555 cubic yards, at 25 cents | 8,639 |
| Clay, 515,923 cubic yards, at 15 cents | 77,388 |
| Approaches to locks, docks, and cribs— | |
| Timber— | |
| Oak, 71,289 feet B. M., at $50 per M | 3,564 |
| Hemlock, 5,919,868 feet B. M., at $23 per M | 136,157 |
| Pine, 1,577,428 feet B. M., at $30 per M | 47,323 |
| Stone fill, 90,985 cubic yards, at 60 cents | 54,591 |
| Iron driftbolts, 660,987 pounds, at 3 cents | 19,830 |
| Retaining walls, 4,490 cubic yards, at $4 | 17,960 |
| Rock-filled dam, 88,532 cubic yards, at 50 cents | 44,266 |
| Back fill, 195,878 cubic yards, at 25 cents | 48,969 |
| Lock No. 2 (Clarks Point) | 864,003 |
| Lock-operating machinery | 100,000 |
| Right of way, 54 acres, at $75 | 4,050 |
| Total estimated cost of section 9 | 1,680,858 |

*Section 10.*—The higher velocities occur off Goose Neck Island and Bradford Hill. The maximum observed velocities at these points were 6.8 and 8.8 feet per second, respectively.

The estimated quantities and cost are as follows:

| | |
|---|---|
| Excavation under water: | |
| Rock, 9,750 cubic yards, at $2.50 | $24,375 |
| Hard material, 2,437,748 cubic yards, at 25 cents | 609,437 |
| Excavation in the dry, on Dry Island, hard material, 75,720 cubic yards, at 25 cents | 18,930 |
| Right of way, 5 acres, at $75 | 375 |
| Total estimated cost of section 10 | 653,117 |

It is proposed to pass the swift water existing between Croills Island and Cornwall, including the Long Sault, with a land canal, earth section, leaving the St. Lawrence at Richards Point and entering the same near the mouth of Grass River. The distance between these points is 10.57 miles. The maximum observed velocity off Richards Point below the entrance of the proposed canal was 4.8 feet per sec-

ond. A guard crib 300 feet long at this entrance is included in the estimate.

The entrance to the St. Lawrence Power Company's canal is about 2 miles below the entrance to the proposed canal. The difference in elevation of the water surface at these entrances is 3.9 feet.

The sectional area of the St. Lawrence Power Company's canal is 5,625 square feet; average width, 225 feet; depth of water, 25 feet, and its mean velocity is estimated to be 4.47 feet per second when its maximum water power is utilized. It would require a velocity of 3.2 feet per second in the proposed ship canal to supply the maximum needs of the power canal. This velocity will give a fall of 0.5 foot between stations 5075 and 5223. The elevation of standard low water at the entrance of the proposed canal is 205. At the intersection of the two canals it would be 204.5. The elevation of water at the entrance to the power canal is 201.1. Its elevation at the intersection would be 200.1. An increased head to the power canal of 4.4 feet would exist at the point of intersection. No estimate has been made of the effect of this increased head or of the cost of controlling gates on the power canal between the proposed ship canal and the St. Lawrence River.

To reduce the velocity and aid navigation at the intersection of these canals the area of the proposed canal is practically doubled, decreasing to a standard section 1,000 feet above the point of intersection. The yardage estimated as necessary for this purpose is 459,330 cubic yards more than that required for a standard section.

Above the lock for a distance of 9,700 feet embankments are necessary. The estimated yardage for this purpose is based on an embankment 50 feet wide, 2 to 1 slopes, and the top at the same elevation as the adjacent slope wall. Its average height is 11 feet, its maximum height for a short distance is 28.5 feet. The embankment will rest upon a stratum of soft blue clay over a portion of its length. At such points it may be necessary to construct the embankment at a safe distance from the excavated prism. Right of way is ample for such modification, and the estimated quantities would remain unchanged.

No rock exists at the entrance at Richards Point or at the crossing of the St. Lawrence Power Company's canal, and no separation has been made for the relatively small amount of material to be excavated under water.

The estimated quantities and cost of the same for section 11 are as follows:

| | |
|---|---|
| Excavation: | |
| Rock, 187,060 cubic yards, at 65 cents | $121,589 |
| Hardpan, 6,895,286 cubic yards, at 35 cents | 2,413,350 |
| Hard material, 3,964,744 cubic yards, at 25 cents | 991,186 |
| Clay, 8,518,415 cubic yards, at 15 cents | 1,277,762 |
| Sand, 956,364 cubic yards, at 15 cents | 143,455 |
| Gravel, 610,933 cubic yards, at 15 cents | 91,640 |

| | |
|---|---|
| Excavation—Continued. | |
| Guard crib— | |
| Timber— | |
| Hemlock, 683,376 feet B. M., at $23 per M | $15,718 |
| Pine, 163,536 feet B. M., at $30 per M | 4,906 |
| Stone fill, 10,350 cubic yards, at 60 cents | 6,210 |
| Iron drift bolts, 76,385 pounds, at 3 cents | 2,291 |
| Embankment, 586,927 cubic yards, at 15 cents | 88,039 |
| Slope walls, 212,120 square yards, at $1.10 | 233,332 |
| Surface drainage | 200 |
| Right of way, 1,110 acres, at $75 | 83,250 |
| Highways, 4.6 miles, at $200 | 920 |
| Highway crossing, steam ferry | 20,000 |
| Total estimated cost of section 11 | 5,493,848 |

*Section 12.*—The lift of the lock is 47.7 feet at standard low water. The elevations of rock average about 2 feet above the grade of the bottom of the canal below the lock.

The high water at Richard's Point is 4 feet, and in the vicinity of the mouth of Grass River it is 3.4 feet above standard low water. Ice jams will raise the water at the lower gates in exceptional cases nearly 30 feet above standard low water.

The estimated quantities and cost of same are as follows:

| | |
|---|---|
| Excavation in the dry: | |
| Rock, 99,810 cubic yards, at 65 cents | $64,876 |
| Hardpan, 775,043 cubic yards, at 35 cents | 271,265 |
| Hard material, 306,172 cubic yards, at 25 cents | 76,543 |
| Clay, 1,100,101 cubic yards, at 15 cents | 165,015 |
| Sand, 72,577 cubic yards, at 15 cents | 10,886 |
| Approaches to locks, docks, and cribs: | |
| Timber: | |
| Oak, 79,680 feet B. M., at $50 per M | 3,984 |
| Hemlock, 7,016,304 feet B. M., at $23 per M | 161,375 |
| Pine, 1,778,124 feet B. M., at $30 per M | 53,344 |
| Stone fill, 115,348 cubic yards, at 60 cents | 69,209 |
| Iron drift bolts, 749,020 pounds, at 3 cents | 22,470 |
| Lock No. 3 (Massena) | 1,667,422 |
| Lock-operating machinery | 100,000 |
| Back fill, 488,410 cubic yards, at 25 cents | 122,103 |
| Right of way, 183 acres, at $75 | 13,725 |
| Total estimated cost of section 12 | 2,802,217 |

*Section 13.*—Considerable soft blue clay exists on this section. The maximum cut is 79 feet. Rock for slope walls is not found in the excavation.

The estimated quantities and cost of same are as follows:

| | |
|---|---|
| Excavation in the dry: | |
| Hardpan, 1,888,411 cubic yards, at 35 cents | $660,944 |
| Hard material, 41,473 cubic yards, at 25 cents | 10,368 |
| Clay, 6,295,996 cubic yards, at 15 cents | 944,399 |
| Sand, 451,686 cubic yards, at 15 cents | 67,753 |
| Slope walls, 53,853 square yards, at $1.45 | 78,087 |
| Right of way, 393 acres, at $75 | 29,475 |
| Total estimated cost of section 13 | 1,791,026 |

*Section 14.*—The average width of Grass River near its mouth is 600 feet at standard low water, or at an elevation of 157 feet: at an elevation of 170 feet, the average width is about 850 feet. When the St. Lawrence Power Company's canal has been developed to its maximum capacity, it will increase the discharge of Grass River by 25,300 cubic feet per second. Polly's Gut, to the north of the proposed sailing course, has an observed velocity of 10 feet per second. The maximum observed velocity about 1,000 feet above the New York and Ottawa Railway bridge was 6.5 feet per second. The headroom at this bridge is approximately 40 feet at standard low water.

Borings taken in the vicinity of St. Regis Island and near the sailing course off Clark's Island indicate that hard material may be encountered down to Hamilton Island, and that below this island the material is sand. Therefore, the classification of material below Station 5930 has been made upon this basis.

The quantities to be excavated under water are:

| | |
|---|---|
| Hard material, 2,007,839 cubic yards, at 25 cents | $501,960 |
| Sand, 1,980,485 cubic yards, at 15 cents | 297,073 |
| New York and Ottawa Railway bridge | 222,888 |
| Total estimated cost for section 14 | 1,021,921 |

SUMMARY FOR 30-FOOT CHANNEL.

| | |
|---|---|
| Section 1 | $9,837,532 |
| Section 2 | 1,777,270 |
| Section 3 | 1,102,510 |
| Section 4 | 648,763 |
| Section 5 | 358,197 |
| Section 6 | 991,237 |
| Section 7 | 202,443 |
| Section 8 | 3,924,915 |
| Section 9 | 1,680,858 |
| Section 10 | 53,117 |
| Section 11 | 5,493,848 |
| Section 12 | 2,802,217 |
| Section 13 | 1,791,026 |
| Section 14 | 1,021,921 |
| Total | 32,285,854 |

NOTE.—The difference between the total and that given in Table No. 8 is due to not carrying the multiplication out further.

DETAILED ESTIMATES—21-FOOT CHANNEL.

The center line, the right of way, the dams, and the general river improvements at the North Galops Channel and at Long Point and Point Rockway are identical with the same items in the estimate of the channel of 30-foot depth. The principal exception to the modification of quantities caused by raising the grade line 9 feet is a canal of 25 feet instead of 21 feet depth from the entrance to the land canal at Richards Point down to the intersection of the proposed canal with the St. Lawrence Power Company's canal. The width at grade is 215

feet, and its sectional area 6,680 square feet. This increase in area is made in order to decrease the velocity through the proposed canal when the power canal is being utilized to its full capacity. The resulting velocity in the proposed canal is 3.78 feet per second, and the fall from Richards Point to the intersection of the two canals is 1 foot.

This reduces the difference between the grade lines of the proposed canals of 21 and 30 feet depth to 8.5 feet instead of 9 feet from the intersection with the power canal down to the Massena Valley lock.

The yardage of rock to be excavated in the dry is not as large as will be required for concrete masonry, stone filling in docks and cribs, and in rock-filled dams on sections 1, 2, and 9. Considerable rock, classified under "Excavation under water," could be excavated in the dry by building protection levees. Also on these sections rock outcroppings appear within short distances.

Rock excavation on sections 5 and 7 will about equal the amount of rock required for slope walls and stone filling in the guard crib.

The rock excavation on section 11 will furnish but a small per cent of the amount required for slope walls and lock construction, while no rock exists in section 12. No rock outcroppings were found in the vicinity of these sections.

The estimated quantities and cost of excavation and construction for the various sections follow:

TABLE No. 7.—*Estimate 21-foot channel.*

| | |
|---|---|
| Section 1: | |
| Excavation under water— | |
| Rock, 921,005 cubic yards, at $2.50 | $2,302,512 |
| Hard material, 400,091 cubic yards, at 25 cents | 100,023 |
| Clay, 29,292 cubic yards, at 15 cents | 4,394 |
| Gravel, 49,610 cubic yards, at 15 cents | 7,441 |
| Excavation in the dry— | |
| Rock, 3,354 cubic yards, at 65 cents | 2,180 |
| Hard material, 100,414 cubic yards, at 25 cents | 25,104 |
| Gravel, 6,747 cubic yards, at 15 cents | 1,012 |
| The improvement of the North Galops Channel, the same as for the 30-foot channel | 2,074,157 |
| Rock-filled dams, 119,444 cubic yards, at 50 cents | 59,722 |
| Right of way, same as for the 30-foot channel | 15,800 |
| Total estimated cost of section 1 | 4,592,345 |
| Section 2: | |
| Excavation under water— | |
| Hardpan, 12,200 cubic yards, at $1 | 12,200 |
| Hard material, 32,010 cubic yards, at 25 cents | 8,002 |
| Clay, 96,585 cubic yards, at 15 cents | 14,488 |
| Excavation in the dry— | |
| Rock, 126,544 cubic yards, at 65 cents | 82,253 |
| Hardpan, 91,589 cubic yards, at 35 cents | 32,056 |
| Hard material, 82,122 cubic yards, at 25 cents | 20,531 |
| Clay, 45,258 cubic yards, at 15 cents | 6,788 |

| | |
|---|---|
| Section 2—Continued. | |
| Approaches to locks (docks)— | |
| Timber— | |
| Oak, 79,680 feet B. M., at $50 per M | $3,984 |
| Hemlock, 4,356,320 feet B. M., at $23 per M | 100,195 |
| Pine, 1,606,632 feet B. M., at $30 per M | 48,199 |
| Stone fill, 71,716 cubic yards, at 60 cents | 43,030 |
| Iron drift bolts, 535,090 pounds, at 3 cents | 16,053 |
| Retaining walls, 6,233 cubic yards, at $4 | 24,932 |
| Rock-filled dam, 50,046 cubic yards, at 50 cents | 25,023 |
| Back fill, 66,768 cubic yards, at 25 cents | 16,692 |
| Lock No. 1 (Sheldon Island) | 541,141 |
| Lock operating machinery | 100,000 |
| Right of way, same as for 30-foot channel | 7,700 |
| Total estimated cost of section 2 | 1,103,267 |
| Section 3, same as for 30-foot channel | 1,102,510 |
| Section 4, same as for 30-foot channel | 648,763 |
| Section 5: | |
| Excavation under water— | |
| Rock, 368 cubic yards, at $2.50 | 920 |
| Hard material, 25,301 cubic yards, at 25 cents | 6,325 |
| Clay, 20,850 cubic yards, at 15 cents | 3,128 |
| Gravel, 7,965 cubic yards, at 15 cents | 1,195 |
| Excavation in the dry— | |
| Rock, 16,493 cubic yards, at 65 cents | 10,722 |
| Hard material, 563,546 cubic yards, at 25 cents | 140,886 |
| Clay, 70,005 cubic yards, at 15 cents | 10,501 |
| Guard crib at entrance— | |
| Timber— | |
| Hemlock, 498,460 feet B. M., at $23 per M | 11,465 |
| Pine, 163,536 feet B. M., at $30 per M | 4,906 |
| Stone fill, 7,860 cubic yards, at 60 cents | 4,716 |
| Iron drift bolts, 58,485 pounds, at 3 cents | 1,755 |
| Slope walls, 8,125 square yards, at $1.10 | 8,937 |
| Right of way, same as for the 30-foot channel | 3,525 |
| Total estimated cost of section 5 | 208,981 |
| Section 6: | |
| Excavation under water— | |
| Rock, 104,513 cubic yards, at $2.50 | 261,282 |
| Hard material, 322,999 cubic yards, at 25 cents | 80,750 |
| Clay, 16,640 cubic yards, at 15 cents | 2,496 |
| Gravel, 10,753 cubic yards, at 15 cents | 1,613 |
| Total estimated cost of section 6 | 346,141 |
| Section 7: | |
| Excavation in the dry— | |
| Rock, 7,745 cubic yards, at 65 cents | 5,034 |
| Hard material, 197,880 cubic yards, at 25 cents | 49,470 |
| Clay, 2,756 cubic yards, at 15 cents | 413 |
| Gravel, 481,258 cubic yards, at 15 cents | 72,189 |
| Slope walls, 11,500 square yards, at $1.10 | 12,650 |
| Right of way, same as for 30-foot channel | 5,700 |
| Total estimated cost of section 7 | 145,456 |

| | |
|---|---|
| Section 8: | |
| Excavation under water— | |
| Rock, 447,990 cubic yards, at $2.50 | $1,119,975 |
| Hard material, 95,394 cubic yards, at 25 cents | 23,849 |
| Clay, 555,395 cubic yards, at 15 cents | 83,309 |
| Gravel, 153,856 cubic yards, at 15 cents | 23,078 |
| Excavation in the dry— | |
| Rock, 49,027 cubic yards, at 65 cents | 31,868 |
| Hard material, 98,516 cubic yards, at 25 cents | 24,629 |
| Gravel, 74,604 cubic yards, at 15 cents | 11,191 |
| Right of way, same as for the 30-foot channel | 1,500 |
| Water-power and mill properties, same as for the 30-foot channel | 100,000 |
| Total estimated cost of section 8 | 1,419,399 |
| Section 9: | |
| Excavation under water— | |
| Rock, 432 cubic yards, at $2.50 | 1,080 |
| Hardpan, 52,771 cubic yards, at $1 | 52,771 |
| Clay, 23,253 cubic yards, at 15 cents | 3,488 |
| Excavation in the dry— | |
| Rock, 51,446 cubic yards, at 65 cents | 33,440 |
| Hardpan, 206,135 cubic yards, at 35 cents | 72,147 |
| Clay, 402,038 cubic yards, at 15 cents | 60,306 |
| Approaches to locks, docks, and cribs— | |
| Timber— | |
| Oak, 79,680 feet B. M., at $50 per M | 3,984 |
| Hemlock, 5,635,240 feet B. M., at $23 per M | 129,611 |
| Pine, 1,857,504 feet B. M., at $30 per M | 55,725 |
| Stone fill, 95,967 cubic yards, at 60 cents | 57,580 |
| Iron drift bolts, 632,760 pounds, at 3 cents | 18,983 |
| Rock-filled dam, 88,532 cubic yards, at 50 cents | 44,266 |
| Back fill, 124,636 cubic yards, at 25 cents | 31,159 |
| Lock No. 2 (Clarks Point) | 571,506 |
| Lock operating machinery | 100,000 |
| Right of way, same as for the 30-foot channel | 4,050 |
| Total estimated cost of section 9 | 1,240,096 |
| Section 10: | |
| Excavation under water, hard material, 494,765 cubic yards, at 25 cents | 123,691 |
| Excavation in the dry, hard material, 49,120 cubic yards, at 25 cents | 12,280 |
| Right of way, same as for the 30-foot channel | 375 |
| Total estimated cost of section 10 | 136,346 |
| Section 11: | |
| Excavation in the dry— | |
| Rock, 14,823 cubic yards, at 65 cents | 9,635 |
| Hardpan, 5,490,943 cubic yards, at 35 cents | 1,921,830 |
| Hard material, 3,226,583 cubic yards, at 25 cents | 806,646 |
| Clay, 7,479,665 cubic yards, at 15 cents | 1,121,950 |
| Sand, 935,842 cubic yards, at 15 cents | 140,376 |
| Gravel, 637,275 cubic yards, at 15 cents | 95,591 |

| | |
|---|---|
| Section 11—Continued. | |
| Guard crib— | |
| Timber— | |
| Hemlock, 498,460 feet B. M., at $23 per M | $11,465 |
| Pine, 163,536 feet B. M., at $30 per M | 4,906 |
| Stone fill, 7,860 cubic yards, at 60 cents | 4,716 |
| Iron drift bolts, 58,485 pounds, at 3 cents | 1,755 |
| Embankment, 574,420 cubic yards, at 15 cents | 86,163 |
| Slope walls, 212,518 square yards, at $1.10 | 233,770 |
| Surface drainage, same as for the 30-foot channel | 200 |
| Right of way, same as for the 30-foot channel | 83,250 |
| Highways, same as for the 30-foot channel | 920 |
| Highway crossings, same as for the 30-foot channel | 20,000 |
| Total estimated cost of section 11 | 4,543,173 |
| Section 12: | |
| Excavation in the dry— | |
| Rock, 18,888 cubic yards, at 65 cents | 12,277 |
| Hardpan, 666,739 cubic yards, at 35 cents | 233,358 |
| Hard material, 201,647 cubic yards, at 25 cents | 50,412 |
| Clay, 816,135 cubic yards, at 15 cents | 122,420 |
| Sand, 71,855 cubic yards, at 15 cents | 10,778 |
| Approaches to locks, docks, and cribs— | |
| Timber— | |
| Oak, 79,680 feet B. M., at $50 per M | 3,984 |
| Hemlock, 5,393,320 feet B. M., at $23 per M | 124,046 |
| Pine, 1,184,664 feet B. M., at $30 per M | 35,540 |
| Stone fill, 92,120 cubic yards, at 60 cents | 55,272 |
| Iron driftbolts, 608,820 pounds, at 3 cents | 18,264 |
| Lock No. 3 (Massena) | 1,086,042 |
| Lock-operating machinery | 100,000 |
| Back fill, 399,890 cubic yards, at 25 cents | 99,973 |
| Right of way, same as for the 30-foot channel | 13,725 |
| Total estimated cost of section 12 | 1,966,091 |
| Section 13: | |
| Excavation in the dry— | |
| Hardpan, 983,931 cubic yards, at 35 cents | 344,376 |
| Hard material, 239,485 cubic yards, at 25 cents | 59,871 |
| Clay, 5,722,842 cubic yards, at 15 cents | 858,426 |
| Sand, 463,422 cubic yards, at 15 cents | 69,513 |
| Slope walls, 54,100 squar yards, at $1.45 | 78,445 |
| Right of way, same as for the 30-foot channel | 29,475 |
| Total estimated cost of section 13 | 1,440,106 |

*Section 14.*—From the existing charts no excavation is found necessary for a ship canal of 21 feet depth from the end of section 13 to Station 7283.

| | |
|---|---|
| New York and Ottawa Railway bridge | $222,888 |

SUMMARY FOR 21-FOOT CHANNEL.

| | |
|---|---|
| Section 1 | $4,592,345 |
| Section 2 | 1,103,267 |
| Section 3 | 1,102,510 |
| Section 4 | 648,763 |
| Section 5 | 208,981 |
| Section 6 | 346,141 |
| Section 7 | 145,456 |
| Section 8 | 1,419,399 |
| Section 9 | 1,240,096 |
| Section 10 | 136,346 |
| Section 11 | 4,543,173 |
| Section 12 | 1,966,091 |
| Section 13 | 1,440,106 |
| Section 14 | 222,888 |
| Total | 19,115,562 |

NOTE.—**The difference between the total and that given in Table No. 9 is due to not carrying the multiplication out farther.**

Tables Nos. 8 and 9 give a summary of the quantities and costs of the 30 and 21 foot channels, respectively.

Table No. 10 gives the location, lifts, and costs of the various locks for both 30 and 21 foot channels.

Tables Nos. 11 and 12 give a classification of the kinds of channels of the proposed 30 and 21 foot channels, respectively.

TABLE NO. 8.—*Summary of quantities and cost—30-foot channel.*

| Classification of material. | Unit of quantity. | Quantities in section— | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1. | 2. | 3. | 4. | 5. | 6. |
| Excavation under water: | | | | | | | |
| Rock | Cubic yards | 3,506,550 | 33,459 | | 61,348 | 23,626 | 340,557 |
| Hardpan | do | | 112,788 | 818,948 | | | |
| Hard material | do | 1,325,388 | 311,926 | | 1,101,611 | 46,245 | 497,450 |
| Clay | do | | 89,643 | 7,160 | | 57,860 | 90,350 |
| Gravel | do | 106,050 | 6,144 | | | 28,275 | 12,868 |
| Excavation in the dry: | | | | | | | |
| Rock | do | 617,480 | 267,850 | | 105,317 | 104,195 | |
| Hardpan | do | | 106,492 | 680,631 | | | |
| Hard material | do | 963,407 | 85,993 | | 595,036 | 638,665 | |
| Clay | do | | 48,911 | 277,110 | | 75,560 | |
| Gravel | do | 41,112 | | | | | |
| Back fill | do | | 105,128 | | | | |
| Retaining walls | do | | 4,849 | | | | |
| Slope walls | Square yards | | | | | 8,125 | |
| Docks and cribs: | | | | | | | |
| Oak | Feet B. M | | 79,680 | | | | |
| Hemlock | do | | 5,588,962 | | | 538,620 | |
| Pine | do | | 1,594,432 | | | 163,536 | |
| Stone fill | Cubic yards | | 88,441 | | | 8,400 | |
| Iron, driftbolts | Pounds | | 652,005 | | | 62,585 | |
| Rock-filled dams | Cubic yards | 119,444 | 50,046 | | | | |
| Right of way | Acres | 124 | 20 | 36 | 37 | 47 | |
| Islands near Galops | | $6,500 | $6,250 | | | | |

TABLE No. 8.—*Summary of quantities and cost—30-foot channel*—Continued.

| Classification of material. | Unit of quantity. | Quantities in section— 7. | 8. | 9. | 10. | 11. | 12. |
|---|---|---|---|---|---|---|---|
| Excavation under water: | | | | | | | |
| Rock | Cubic yards | | 1,396,943 | 12,230 | 9,750 | | |
| Hard material | do | | 301,827 | 144,100 | 2,437,748 | | |
| Clay | do | | 715,477 | 172,069 | | | |
| Gravel | do | | 236,336 | | | | |
| Excavation in the dry: | | | | | | | |
| Rock | do | 61,129 | 113,883 | 129,515 | | 187,060 | 99,810 |
| Hardpan | do | | | 221,494 | | 6,895,286 | 775,043 |
| Hard material | do | 217,969 | 106,736 | 34,555 | 75,720 | 3,964,744 | 306,172 |
| Clay | do | 3,404 | | 515,923 | | 8,518,415 | 1,100,101 |
| Sand | do | | | | | 956,364 | 72,577 |
| Gravel | do | 595,707 | 80,808 | | | 610,933 | |
| Embankments | do | | | | | 586,927 | |
| Back fill | do | | | 195,878 | | | 488,410 |
| Retaining walls | do | | | 4,490 | | | |
| Slope walls | Square yards | 11,500 | | | | 212,120 | |
| Docks and cribs: | | | | | | | |
| Oak | Feet B. M | | | 71,280 | | | 79,680 |
| Hemlock | do | | | 5,919,868 | | 683,376 | 7,016,304 |
| Pine | do | | | 1,577,428 | | 163,536 | 1,778,124 |
| Stone fill | Cubic yards | | | 90,985 | | 10,350 | 115,348 |
| Iron, driftbolts | Pounds | | | 660,987 | | 76,385 | 749,020 |
| Highways | Miles | | | | | 4.6 | |
| Ferry (at highway crossing) | | | | | | 1 | |
| Rock-filled dams | Cubic yards | | | 88,532 | | | |
| Right of way | Acres | 76 | 20 | 54 | 5 | 1,110 | 183 |
| Water power, etc | | | $100,000 | | | | |
| Drainage | | | | | | $200 | |

| Classification of material. | Unit of quantity. | Quantities in section— 13. | 14. | Total quantity. | Unit price. | Amount. |
|---|---|---|---|---|---|---|
| Excavation under water: | | | | | | |
| Rock | Cubic yards | | | 5,384,463 | $2.50 | $13,461,157 |
| Hardpan | do | | | 931,736 | 1.00 | 931,736 |
| Hard material | do | | 2,007,839 | 8,174,134 | .25 | 2,043,534 |
| Clay | do | | | 1,127,559 | .15 | 169,133 |
| Sand | do | | 1,980,485 | 1,980,485 | .15 | 297,073 |
| Gravel | do | | | 389,673 | .15 | 58,451 |
| Excavation in the dry: | | | | | | |
| Rock | do | | | 1,686,239 | .65 | 1,096,056 |
| Hardpan | do | 1,888,411 | | 10,567,352 | .35 | 3,698,573 |
| Hard material | do | 41,473 | | 7,030,470 | .25 | 1,757,617 |
| Clay | do | 6,295,996 | | 16,835,420 | .15 | 2,525,313 |
| Sand | do | 451,686 | | 1,480,627 | .15 | 222,094 |
| Gravel | do | | | 1,328,560 | .15 | 199,284 |
| Embankments | do | | | 586,927 | .15 | 88,039 |
| Back fill | do | | | 789,416 | .25 | 197,354 |
| Retaining walls | do | | | 9,839 | 4.00 | 37,356 |
| Slope walls | Square yards | 53,853 | | 285,598 | { 1.10 / 1.45 } | 333,006 |
| Docks and cribs: | | | | | | |
| Oak | Feet B. M | | | 230,640 | [1] 50.00 | 11,532 |
| Hemlock | do | | | 19,747,130 | [1] 23.00 | 454,184 |
| Pine | do | | | 5,277,056 | [1] 30.00 | 158,311 |
| Stone fill | Cubic yards | | | 313,524 | .60 | 188,114 |
| Iron, driftbolts | Pounds | | | 2,200,982 | .03 | 66,029 |
| Lock No. 1 (Sheldon Island), operating machinery included. | | | | | | 916,888 |
| Lock No. 2 (Clarks Point), operating machinery included. | | | | | | 964,003 |
| Lock No. 3 (Massena), operating machinery included. | | | | | | 1,767,422 |
| Highways | Miles | | | 4.6 | 200.00 | 920 |
| Ferry (at highway crossing) | | | | 1 | | 20,000 |
| Rock-filled dams | Cubic yards | | | 258,022 | .50 | 129,011 |
| Right of way | Acres | 393 | | 2,105 | 75.00 | 157,875 |
| Islands near Galops | | | | $12,700 | | 12,700 |
| Water power, etc | | | | 100,000 | | 100,000 |
| Drainage | | | | $200 | | 200 |
| Railroad bridge | | | 1 | 1 | | 222,888 |
| Total | | | | | | 32,285,853 |

[1] Per 1,000 feet.

TABLE No. 9.—*Summary of quantities and cost—21-foot channel.*

| Classification of material. | Unit of quantity. | Quantities in section— | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1. | 2. | 3. | 4. | 5. | 6. |
| Excavation under water: | | | | | | | |
| Rock | Cubic yards | 1,487,913 | | | 61,348 | 368 | 104,513 |
| Hardpan | do | | 12,200 | 818,948 | | | |
| Hard material | do | 626,896 | 32,010 | | 1,101,611 | 25,301 | 322,999 |
| Clay | do | 29,292 | 96,585 | 7,160 | | 20,850 | 16,640 |
| Gravel | do | 49,610 | | | | 7,965 | 10,753 |
| Excavation in the dry: | | | | | | | |
| Rock | do | 595,798 | 126,544 | | 105,317 | 16,496 | |
| Hardpan | do | | 91,589 | 680,631 | | | |
| Hard material | do | 960,803 | 82,122 | | 595,036 | 563,546 | |
| Clay | do | | 45,258 | 277,110 | | 70,005 | |
| Gravel | do | 6,747 | | | | | |
| Back fill | do | | 66,768 | | | | |
| Retaining walls | do | | 6,233 | | | | |
| Slope walls | Square yards | | | | | 8,125 | |
| Docks and cribs: | | | | | | | |
| Oak | Feet B. M | | 79,680 | | | | |
| Hemlock | do | | 4,356,320 | | | 498,460 | |
| Pine | do | | 1,606,632 | | | 163,536 | |
| Stone fill | Cubic yards | | 71,716 | | | 7,860 | |
| Iron, driftbolts | Pounds | | 535,000 | | | 58,485 | |
| Rock-filled dams | Cubic yards | 119,444 | 50,046 | | | | |
| Right of way | Acres | 124 | 20 | 36 | 37 | 47 | |
| Islands near Galops | | $6,500 | $6,200 | | | | |

| Classification of material. | Unit of quantity. | Quantities in section— | | | | | |
|---|---|---|---|---|---|---|---|
| | | 7. | 8. | 9. | 10. | 11. | 12. |
| Excavation under water: | | | | | | | |
| Rock | Cubic yards | | 447,990 | 432 | | | |
| Hardpan | do | | | 52,771 | | | |
| Hard material | do | | 93,394 | | 494,765 | | |
| Clay | do | | 555,395 | 23,253 | | | |
| Gravel | do | | 153,856 | | | | |
| Excavation in the dry: | | | | | | | |
| Rock | do | 7,745 | 49,027 | 51,446 | | 14,823 | 18,888 |
| Hardpan | do | | | 206,135 | | 5,490,943 | 666,739 |
| Hard material | do | 197,880 | 98,516 | | 49,120 | 3,226,583 | 201,647 |
| Clay | do | 2,756 | | 402,038 | | 7,479,665 | 816,135 |
| Sand | do | | | | | 935,842 | 71,855 |
| Gravel | do | 481,258 | 74,604 | | | 637,275 | |
| Embankments | do | | | | | 574,420 | |
| Back fill | do | | | 124,636 | | | 399,890 |
| Slope walls | Square yards | 11,500 | | | | 212,518 | |
| Docks and cribs: | | | | | | | |
| Oak | Feet B. M | | | 79,680 | | | 79,680 |
| Hemlock | do | | | 5,635,240 | | 498,460 | 5,393,320 |
| Pine | do | | | 1,857,504 | | 163,536 | 1,184,664 |
| Stone fill | Cubic yards | | | 95,967 | | 7,860 | 92,120 |
| Iron driftbolts | Pounds | | | 632,760 | | 58,485 | 608,820 |
| Highways | Miles | | | | | 4.6 | |
| Ferry (at highway crossing). | | | | | | 1 | |
| Rock filled dams | Cubic yards | | | 88,532 | | | |
| Right of way | Acres | 76 | 20 | 54 | 5 | 1,110 | 183 |
| Water power, etc | | | $100,000 | | | | |
| Drainage | | | | | | $200 | |

TABLE NO. 9.—*Summary of quantities and cost—21-foot channel*—Continued.

| Classification of material. | Unit of quantity. | Quantities in section— 13. | Quantities in section— 14. | Total quantity. | Unit price. | Amount. |
|---|---|---|---|---|---|---|
| Excavation under water: | | | | | | |
| Rock | Cubic yards | | | 2,102,504 | $2.50 | $5,256,410 |
| Hardpan | do | | | 883,919 | 1.00 | 883,919 |
| Hard material | do | | | 2,698,976 | .25 | 674,744 |
| Clay | do | | | 749,175 | .15 | 112,376 |
| Gravel | do | | | 222,184 | .15 | 33,327 |
| Excavation in the dry: | | | | | | |
| Rock | do | | | 986,084 | .65 | 640,954 |
| Hardpan | do | 983,931 | | 8,119,968 | .35 | 2,841,988 |
| Hard material | do | 239,485 | | 6,214,738 | .25 | 1,553,684 |
| Clay | do | 5,722,842 | | 14,815,809 | .15 | 2,222,371 |
| Sand | do | 463,422 | | 1,471,119 | .15 | 220,667 |
| Gravel | do | | | 1,199,884 | .15 | 179,982 |
| Embankments | do | | | 574,420 | .15 | 86,163 |
| Back fill | do | | | 591,294 | .25 | 147,823 |
| Retaining walls | do | | | 6,233 | 4.00 | 24,932 |
| Slope walls | Square yards | 54,100 | | 286,243 | 1.10<br>1.45 | 333,802 |
| Docks and cribs: | | | | | | |
| Oak | Feet B. M. | | | 239,040 | [1]50.00 | 11,952 |
| Hemlock | do | | | 16,381,800 | [1]23.00 | 376,781 |
| Pine | do | | | 4,975,872 | [1]30.00 | 149,276 |
| Stone fill | Cubic yards | | | 275,523 | .60 | 165,314 |
| Iron driftbolts | Pounds | | | 1,893,640 | .03 | 56,809 |
| Lock No. 1 (Sheldon Island), operating machinery included. | | | | | | 641,141 |
| Lock No. 2 (Clarks Point), operating machinery included. | | | | | | 671,506 |
| Lock No. 3 (Massena), operating machinery included. | | | | | | 1,186,042 |
| Highways | Miles | | | 4.6 | 200.00 | 920 |
| Ferry at highway crossing | | | | 1 | | 20,000 |
| Rock-filled dams | Cubic yards | | | 258,022 | .50 | 129,011 |
| Right of way | Acres | 393 | | 2,105 | $75.00 | 157,875 |
| Islands near Galops | | | | 12,700 | | 12,700 |
| Water power, etc | | | | $100,000 | | 100,000 |
| Drainage | | | | $200 | | 200 |
| Railroad bridge | | | 1 | 1 | | 222,888 |
| Total | | | | | | 19,115,557 |

[1]Per 1,000 feet.

TABLE NO. 10.

| No. of lock. | Location. | Station. | Kind. | Elevation (standard low water). Above. | Elevation (standard low water). Below. | Lift, in feet. | Length of level, in miles. |
|---|---|---|---|---|---|---|---|
| 1 | Sheldon Island | 3779 | Single | 242.7 | 233.0 | 9.7 | |
| 2 | Clarks Point | 4372 | do | 225.7 | 213.9 | 11.8 | 11.2 |
| 3 | Massena | 5508 | do | 204.5 | 156.8 | 47.7 | 21.5 |

*Cost of locks.*

| No. of lock. | 30-foot channel. | 21-foot channel. | Operating machinery |
|---|---|---|---|
| 1 | $816,888 | $541,141 | $100,000 |
| 2 | 864,003 | 471,506 | 100,000 |
| 3 | 1,667,422 | 1,086,042 | 100,000 |
| Total | 3,348,313 | 2,198,689 | 300,000 |
| Operating machinery | 300,000 | 300,000 | |
| Total cost | 3,648,313 | 2,498,689 | |

Stations showing location of head of locks, as given in Table No. 10, are for the 30-foot channel. The location of the locks for the 21-foot channel does not correspond exactly with the locks of the 30-foot channel.

*Classification of channel, 30-foot depth.*

| Station. From— | Station. To— | Open water. | Improved river. | Canal, earth section. | Lock and approaches. |
|---|---|---|---|---|---|
| 0 | 3481 | 348,100 | | | |
| 3481 | 3498 | | 1,700 | | |
| 3498 | 3572 | 7,400 | | | |
| 3572 | 3762+29 | | 19,029 | | |
| 3762+29 | 3802 | | | | 3,971 |
| 3802 | 3819 | | 1,700 | | |
| 3819 | 3856 | 3,700 | | | |
| 3856 | 3885 | | 2,900 | | |
| 3885 | 3999 | 11,400 | | | |
| 3999 | 4066 | | 6,700 | | |
| 4066 | 4206 | 14,000 | | | |
| 4206 | 4213 | | 700 | | |
| 4213 | 4229 | | | 1,600 | |
| 4229 | 4257 | | 2,800 | | |
| 4257 | 4278 | | | 2,100 | |
| 4278 | 4356+10 | | 7,810 | | |
| 4356+10 | 4395+81 | | | | 3,971 |
| 4395+81 | 4460 | | 6,419 | | |
| 4460 | 4470 | 1,000 | | | |
| 4470 | 4481 | | 1,100 | | |
| 4481 | 4490 | 900 | | | |
| 4490 | 4610 | | 12,000 | | |
| 4610 | 4626 | 1,600 | | | |
| 4626 | 4643 | | 1,700 | | |
| 4643 | 4721 | 7,800 | | | |
| 4721 | 4760 | | 3,900 | | |
| 4760 | 4916 | 15,600 | | | |
| 4916 | 4933 | | 1,700 | | |
| 4933 | 5055 | 12,200 | | | |
| 5055 | 5075 | | 2,000 | | |
| 5075 | 5490+60 | | | 41,560 | |
| 5490+60 | 5532+31 | | | | 4,171 |
| 5532+31 | 5633 | | | 10,069 | |
| 5633 | 5635 | | 200 | | |
| 5635 | 5668 | 3,300 | | | |
| 5668 | 5674 | | 600 | | |
| 5674 | 5682 | 800 | | | |
| 5682 | 5695 | | 1,300 | | |
| 5695 | 5702 | 700 | | | |
| 5702 | 5717 | | 1,500 | | |
| 5717 | 5831 | 11,400 | | | |
| 5831 | 5844 | | 1,300 | | |
| 5844 | 5851 | 700 | | | |
| 5851 | 5872 | | 2,100 | | |
| 5872 | 5885 | 1,300 | | | |
| 5885 | 5893 | | 800 | | |
| 5893 | 5909 | 1,600 | | | |
| 5909 | 5932 | | 2,300 | | |
| 5932 | 5955 | 2,300 | | | |
| 5955 | 5983 | | 2,800 | | |
| 5983 | 6204 | 22,100 | | | |
| 6204 | 6240 | | 3,600 | | |
| 6240 | 6268 | 2,800 | | | |
| 6268 | 6288 | | 2,000 | | |
| 6288 | 6327 | 3,900 | | | |
| 6327 | 6370 | | 4,300 | | |
| 6370 | 6378 | 800 | | | |
| 6378 | 6388 | | 1,000 | | |
| 6388 | 6453 | 6,500 | | | |
| 6453 | 6464 | | 1,100 | | |
| 6464 | 6473 | 900 | | | |
| 6473 | 6482 | | 900 | | |
| 6482 | 6630 | 14,800 | | | |
| 6630 | 6703 | | 7,300 | | |
| 6703 | 6975 | 27,200 | | | |
| 6975 | 7010 | | 3,500 | | |
| 7010 | 7016 | 600 | | | |
| 7016 | 7028 | | 1,200 | | |
| 7028 | 7083 | 25,500 | | | |
| Total feet | | 550,900 | 109,958 | 55,329 | 12,113 |
| Total miles | | 104.34 | 20.82 | 10.48 | 2.30 |

*Classification of channel, 21-foot depth.*

| Station. From— | Station. To— | Open water. | Improved river. | Canal earth section. | Lock and approaches. |
|---|---|---|---|---|---|
| 0 | 3574 | 357,400 | | | |
| 3574 | 3763 + 29 | | 18,929 | | |
| 3763 + 29 | 3801 + 30 | | | | 3,801 |
| 3801 + 30 | 3856 | 5,470 | | | |
| 3856 | 3885 | | 2,900 | | |
| 3885 | 3969 | 11,400 | | | |
| 3969 | 4066 | | 6,700 | | |
| 4066 | 4209 | 14,300 | | | |
| 4209 | 4213 | | 400 | | |
| 4213 | 4229 | | | 1,600 | |
| 4229 | 4257 | | 2,800 | | |
| 4257 | 4278 | | | 2,100 | |
| 4278 | 4348 | | 7,000 | | |
| 4348 | 4362 + 10 | 1,410 | | | |
| 4362 + 10 | 4400 + 11 | | | | 3,801 |
| 4400 + 11 | 4455 | | 5,489 | | |
| 4455 | 4531 | 7,600 | | | |
| 5431 | 4535 | | 400 | | |
| 4535 | 4569 | 3,400 | | | |
| 4569 | 4578 | | 900 | | |
| 4578 | 4726 | 14,800 | | | |
| 4726 | 4748 | | 2,260 | | |
| 4748 | 4916 | 16,800 | | | |
| 4916 | 4919 | | 300 | | |
| 4919 | 5055 | 13,600 | | | |
| 5055 | 5062 | | 700 | | |
| 5062 | 5065 | 300 | | | |
| 5065 | 5075 | | 1,000 | | |
| 5075 | 5491 + 60 | | | 41,660 | |
| 5491 + 60 | 5531 + 61 | | | | 4,001 |
| 5531 + 61 | 5633 | | | 10,139 | |
| 5633 | 7283 | 165,000 | | | |
| Total feet | | 611,480 | 49,718 | 55,499 | 11,603 |
| Total miles | | 115.81 | 9.42 | 10.51 | 2.20 |

In conclusion, Edw. B. Hitchcock, Glenn D. Holmes, instrument men; Charles F. Howe and George A. Hammond, superintendents of borings, and John Y. Bayliss, George D. Williams, and William P. Boright, recorders, should be mentioned.

I would acknowledge the favors extended and the information furnished by Mr. Tom S. Rubidge, superintending engineer of the St. Lawrence district, Cornwall, Ontario, regarding Canadian gauge readings and soundings through a portion of Lake St. Francis.

Very respectfully,

J. W. BEARDSLEY,
*Assistant Engineer.*

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

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## APPENDIX NO. 12.

### CHAMPLAIN ROUTE, NORTHERN DIVISION.

DETROIT, MICH., *July 27, 1899.*

GENTLEMEN: I have the honor to submit the following report in regard to the surveys and estimates of the cost of a ship canal between Lake Champlain and the St. Lawrence River.

A study of maps of the region between Lake Champlain and the St. Lawrence River in the State of New York shows the country to be mountainous and entirely impracticable for a ship canal.

The country immediately north of the international boundary line is quite high and rolling, with deep valleys. The drainage of this region is to the north and northeast. The most important topographical features are a series of nearly parallel glacial valleys, with ridges of rock between, running nearly north and south in the eastern portion, but swinging to about northeast and southwest as the St. Lawrence is approached.

At a distance of about 10 miles north of the boundary line the hills break down and the country becomes generally level.

In the hilly country adjacent to the boundary line, and about 10 miles west of the village of Champlain, N. Y., are found the headwaters of the Chazy River, which empties into Kings Bay, Lake Champlain; the La Colle River, which flows a little north of east and empties into the Richelieu River; the Little Montreal River, which flows first north, then northeast, and empties into the Richelieu River; Norton Creek, which flows parallel to and about 2 miles west of the Little Montreal for about 10 miles, where it turns to the west and empties into the English River, which flows nearly northwest and empties into the Chateauguay River.

A careful examination of the country bounded on the north by Norton Creek, south by the international boundary line, east by Norton Creek, and west by the Chateauguay River showed that there was no practicable line for a canal south of Norton Creek.

From a point on Norton Creek near Aubrey Station to the St. Lawrence River at Lake St. Francis the country is in general a plain, much of the distance below the level of Lake St. Francis. About midway between these points is the valley of the Chateauguay River, which is 40 feet below the level of Lake St. Francis.

A line drawn from the mouth of the Chazy River to a point on Norton Creek where it turns to the west was found to pass near low divides between the heads of adjacent streams and to offer a practicable route. This is essentially the route suggested by the commission of 1896.

From Aubrey to Lake St. Francis the route suggested by the commission of 1896 did not appear to be the best, inasmuch as it kept to the north, getting on ground so low that embankments from 15 to 25 feet in height would be required for many miles. On this account it was thought best to keep farther south and get on higher ground.

Standard low water in Lake St. Francis, which is practically low water during season of navigation, is 152.39 feet above mean tide at New York. The summit level for the canal has therefore been taken as 152.4, and an effort made to keep on ground which would give embankments of reasonable height. From Aubrey to Ormstown the country immediately adjoining the plains is a solid mass of rock at

an elevation of 220 feet or more. The surveys were kept as close to this rock as practicable. From Aubrey to Champlain the country is all above the level of the lake, and the line was kept on the lowest ground.

The surveys have been made with a degree of care commensurate with the importance of the work, and in accordance with the "General instructions to field parties" (Appendix No. 9).

The levels were run in one direction and checked in the reverse direction. The limit of error allowed was

$$C = 0.05 \text{ feet} \times \sqrt{\text{distance in miles}}.$$

The error was not allowed to exceed this amount, either for the whole or any part of the line.

The levels were started from the United States Coast and Geodetic Survey bench mark on the Chapman Block at Rouse Point, N. Y., with an elevation of 110.06. The field maps and profiles have all been referred to this datum. A later determination of the elevation of this bench mark, made under the direction of Mr. C. L. Harrison, gives the elevation above mean tide in New York Harbor as 108.95, when referred to the bench mark at Greenbush, N. Y., with an elevation of 14.73. All elevations used in this report will be referred to the later datum.

At Valleyfield connection was made with a bench mark on lock No. 14, Beauharnois Canal, established by Mr. Thomas Monro in 1891, by a line of levels brought across from the Chapman Block bench. Our elevation was 0.121 foot higher than his.

From one of our benches near St. Stanislas we carried a line of levels to Hogansburg, N. Y., to connect with a bench mark which had previously been established by Mr. David Molitor.

Wherever the country seemed to offer a choice of locations, alternate lines were run and the topography developed.

The original base line between Ormstown and Lake St. Francis was run via St. Stanislas. An alternate line beginning about 2 miles west of Ormstown was run to the lake, a distance of 9.3 miles. This line is the one used for the location. Another line beginning about 4 miles east of Ormstown was run to the lake, a distance of 16 miles. This line kept to the north of the other lines on lower ground, and the embankment was found to be excessive. On this account no topography was taken. For most of the distance it was outside the limits of the maps and is not shown.

The total length of base line run and leveled was 74.61 miles.

In addition to this a stadia line about 9 miles long was run, and topography taken to develop what is known as the "Bogtown line." It was thought that this line would give less rock excavation than the base-line route, but this proved not to be the case.

The proposed location of the canal in Lakes Champlain and St. Francis was covered by soundings. These soundings are reduced to elevations above mean tide at New York. They were carried out to

a point such that the elevation of the bottom was well below that of the established grade. The United States Coast and Geodetic charts of Lake Champlain and the Canadian charts of the northern end of Lake St. Francis, furnished by Mr. Thomas Monro, together with a line of soundings from the southern end of the Canadian chart to Cherry Island, show a sufficient depth of water along the sailing line.

Borings to determine the character of the materials to be excavated have been made at intervals of 1,000 feet or less on all lines projected and covering a width of from half a mile to a mile. These have in all cases been carried to rock or to the proposed bottom of the canal. Samples of the materials from all holes have been preserved and properly labeled for identification.

In all 1,387 borings were made. In addition to these, four diamond-drill borings have been made to determine the character of the rock. These holes were located as follows:

No. 1, near station 9904 of the proposed canal location.

No. 2, near station 9348 of the proposed canal location.

No. 3, near station 9075 of base line, at Holton Station, on the Canadian Atlantic Railway.

No. 4, near station 8106 of canal location at the crossing of the Chateauguay River.

A report of these borings has been submitted, in Appendix No. 19, by Mr. R. C. Smith, under whose direction they were made.

## CONDITIONS GOVERNING THE LOCATION.

*Lake Champlain.*—The lowest water ever recorded in Lake Champlain was on October 12, 1880, when the reading on the gauge was 0.14. (Appendix No. 7, Report of the United States Coast and Geodetic Survey, 1887, p. 170.) The zero of the gauge is 93.501, and low water 93.361. The Coast Survey report gives the elevation of the zero of the gauge as 94.53.

I had a line of levels run from the Chapman Block bench to zero of gauge and checked by reverse running, the two agreeing within 0.028 foot. Using the mean of the two runnings, the elevation of the zero of the gauge as compared with the Chapman Block bench is 94.61, or 0.08 foot higher than the elevation as given by the Coast Survey. Applying the correction of 1.109 to reduce to Greenbush bench, our elevation of the zero becomes 93.501, as stated, and low water 93.361. The highest water recorded appears to have been on May 4, 1869. This was prior to any records being kept at Fort Montgomery. It was recorded at the railroad bridge of the Central Vermont Railroad at Rouse Point, and is given as being 9.25 feet above low water of October 12, 1880 (Report of United States Deep Waterways Commission, 1896, p. 124), making extreme high water 102.611.

This elevation appears to be well authenticated.

*Lake St. Francis.*—The report of the Canadian Deep Waterways

Commission gives, on the authority of Thomas Monro, esq., member of the commission and engineer of the Soulanges Canal:

Extreme low water, November, 1895, 151.88—0.988 = 150.892.

Extreme high water, 156.80—0.988 = 155.812.

The correction of 0.988 was arrived at as follows:

At Valleyfield our levels were 0.121 foot higher than the bench mark established by Mr. Monro, which being subtracted from 1.109, the correction for Rouse Point bench, gives 0.988 foot.

The elevations of some of the principal points will be given below for more convenient reference:

| | |
|---|---|
| Bench mark on Chapman block, Rouse Point | 108.951 |
| Bench mark, United States Engineers, Fort Montgomery | 94.998 |
| Upper miter sill, lock No. 1, St. Johns[1] | 86.278 |
| Zero of United States Engineers' gauge, Fort Montgomery | 93.501 |
| High water, Lake Champlain | 102.611 |
| Low water, Lake Champlain | 93.361 |
| High water, Lake St. Francis | 155.812 |
| Low water, Lake St. Francis | 150.892 |
| Standard low water, Lake St. Francis | 152.390 |
| Bench mark on lock No. 14, Valleyfield | 155.682 |
| Datum plane for Coast Survey charts, Lake Champlain | 93.861 |

In order to lessen the excavation between Whitehall and Albany, as well as the dredging in Lake Champlain, it is desirable to keep the lake at as high an elevation as practicable. For this reason it was directed by the Board that estimates be based on maintaining the low-water stage of Lake Champlain at an elevation of 100 feet above mean tide at New York by regulating works near the foot of the lake.

It would not be practicable to raise the level of Lake St. Francis, nor would it be desirable to increase the height of the embankments across the valley of the Chateauguay River and the Aubrey Plains.

The elevation of water surface in the summit level has, therefore, been fixed at 152.4, which is the elevation of standard low water in Lake St. Francis.

As the difference between high and low water in Lake St. Francis is 4.92 feet, a guard lock at the entrance of the canal will be necessary.

As before stated, it is desirable to regulate the surface of Lake Champlain so that it will not fall below 100 and at the same time not go materially above the present high-water mark of 102.61. By putting a dam across from Stony Point to Windmill Point and making the crest of the dam 100 the surface would be maintained at 100

[1] The elevation of the miter sill is given in the report of the Deep Waterways Commission for 1896 as 87.41. This appears to be an error. Mr. R. Steckel, engineer in charge of the Canadian geodetic leveling, gives it as 7.22 feet below the zero of the United States Engineers' gauge at Fort Montgomery. The zero of this gauge as used by the commission was 94.53, giving 87.31 for the level of the lock sill, or 86.278 when reduced to the Greenbush datum.

or more, provided the inflow during the dry season was sufficient to supply the evaporation and the minimum amount now flowing in the Richelieu River. As the Chambly Canal takes its water from the river, and as there are valuable power plants at Chambly, the regular flow of the river could not be interfered with.

The report of the United States Deep Waterways Commission for 1896 shows the monthly mean of water levels above the zero of the United States Engineers' gauge at Fort Montgomery for the years 1871 to 1895, inclusive. Col. J. N. Barlow, Corps of Engineers, U. S. Army, furnished the daily record at the same place from January, 1896, to May, 1899, inclusive.

The record of the daily fluctuations for twenty-seven years at lock No. 1, St. Johns, Province of Quebec, was obtained from Ernest Marceau, superintendent engineer of railways and canals, Montreal, Canada. Information was also furnished by Mr. P. P. Benoit, superintendent of the Chambly Canal.

A study of these records for many years shows that the lake is rising from November to May, inclusive, and falling from June to October, inclusive. During the months of August, September, and October the lake appears to fall on the average about 0.25 foot per month, and the river appears to be drawing on the reservoir supply in the lake to a certain extent. A fall of 0.25 foot per month over the area of the lake would furnish a supply of about 1,000 cubic feet per second. Thus it would seem, in order to supply the present flow and maintain the lake at a constant level during the months of August, September, and October, a supply of 1,000 cubic feet per second would have to be supplied through the canal from the St. Lawrence River. In addition to this, enough would have to be drawn from the St. Lawrence to supply the water needed to operate the upper portion of the canal from Whitehall to Albany. As the sectional area of the canal is about 7,500 square feet, this could not create a current of more than a half to three-quarters of a foot per second, which would not be objectionable.

Plate 91 shows the general location and details of the proposed regulating works. At Stony Point and at Windmill Point there are outcrops of rock which is said to be Utica shale. At Windmill Point the rock appears to be close to the surface for some distance back from the point. Between Stony Point and the mainland there is a swamp, in which borings showed mud 5 feet deep and clay 57 feet without striking rock. On the mainland a short distance to the west rock is found in wells at an elevation of about 100.

The borings show a stratum of clay extending from Stony Point to Windmill Point. As the head on the dam would never exceed about 7 feet, a crib dam founded on this clay stratum would undoubtedly be perfectly safe. A lock and sluices can be put in on rock foundations at Stony Point.

As the Canadian government is enlarging its canals to a depth of 14 feet, with locks 42 by 280 feet, the lock would probably have to be of the same dimensions in order to accommodate their traffic on the Richelieu River. Between Stony Point and the mainland an earth embankment would be perfectly safe. The details and estimate of cost of the Champlain regulating works are given in Appendix No. 8.

I have secured the following gauging of the Richelieu River:

| | |
|---|---|
| October 16, 1862, by Mr. Charles Legge;[1] measurement near St. Johns: | |
| Discharge in cubic feet per second | 4,257 |
| September 10, 1894, by Mr. Henry Holgate;[2] measurement near St. Johns: | |
| Reading of gauge at St. Johns | 7.58 |
| Surface of water at St. Johns above tide | 93.85 |
| Discharge in cubic feet per second | 6,390 |
| August 22, 1895, by Mr. Cecil B. Smith;[2] measurement near St. Johns: | |
| Reading of gauge at St. Johns | 7.67 |
| Surface of water at St. Johns above tide | 93.94 |
| Discharge in cubic feet per second | 6,102 |
| October 17, 1895, by Prof. C. H. McLeod;[2] measurement near St. Johns: | |
| Reading of gauge at St. Johns | 7.00 |
| Surface of water at St. Johns above tide | 93.27 |
| Discharge in cubic feet per second | 3,750 |
| 1895, by Shanly and Quirk;[1] measurement near St. Johns: | |
| Discharge in cubic feet per second | 7,000 |

I have not been able to get the date of this, but the water is reported to have been at about the same stage as when measured by Messrs. Holgate and Smith.

| | |
|---|---|
| April 28, 1899, by J. W. Macklin; weir measurement at dam of Chambly Power Company, Chambly, Quebec: | |
| Length of weir ..... feet | 1,625 |
| Depth of water on weir measured to surface of still water above ... do | 3.20 |
| Reading of gauge at St. Johns | 11.75 |
| Surface of water at St. Johns above tide | 99.13 |
| Discharge in cubic feet per second, as computed by Mr. Macklin (passing over weir) | 29,050 |
| Add passing through sluice to mill | 800 |
| Total | 29,850 |

At the time the above gauging was made there was no wind and the river had been at about the same stage for several days. This is probably near a high-water discharge.

The gaugings by Messrs. Holgate and Smith were made with tubes weighted so as to float vertically and reaching nearly to the bottom with but little projecting above the water. That by Professor McLeod was made with an "Amsler mechanical meter."

[1] Furnished by Ernest Marceau, esq., engineer of railways and canals, Montreal Canada.

[2] Furnished by Mr. J. W. Macklin, engineer of the Chambly Power Company.

The low-water measurements are somewhat discordant and hard to reconcile, as there was only a difference of 0.67 foot between the readings of the gauge when the difference was greatest. As the river near St. Johns has a width of about 1,200 feet and a mean depth of 12 to 13 feet, a variation of 0.67 foot ought not to make so great a difference as is shown by the measurements.

*Locks.*—A lock with a lift of 52.4 feet has been located about 4 miles from Lake Champlain and just southeast of the village of Champlain. At this point rock is found at an elevation of 110, giving a rock foundation with the lower 40 feet in rock.

If it should be thought best to substitute two locks with lifts of 26.2 feet each, the lower lock can be put about 6,500 feet farther east on rock foundation. The cost would probably be about the same in either case, but the single lock possesses the advantage of less detention and will somewhat simplify the passing of the water supply for Lake Champlain. In the event of one lock being used, the water can be taken out above the lock and discharged into the Chazy River after being used to generate power for operating the lock, etc. The estimates were made for a canal with only one lock at this point.

As high water in Lake St. Francis is 3.4 feet above standard low water, a guard lock with a maximum lift of 3.4 feet will be necessary near the entrance to the canal. A favorable location has been selected at a point about three-quarters of a mile from the lake, where the surface of the rock has an elevation of 140.

A by-pass of sufficient dimensions to pass 4,000 to 5,000 cubic feet per second will have to be constructed around this lock. The power for operating the lock can conveniently be brought from a power house located at the crossing of the Chateauguay River, where a head of 30 feet would be available.

*Receiving weirs.*—At the crossing of the Chazy River above Champlain the surface of the water in the river is about 12 feet above the level of water in canal. Rock is found at an elevation of about 160. Just below this point there is a dam with a head of 20 feet. The village of Champlain has acquired the right to use whatever water is needed for a supply, as well as the power for pumping.

The surplus power, if any, is owned by Whiteside Brothers, of Champlain.

When this stream was gauged on April 25, 1899, it was carrying 1,038 cubic feet per second. This may be increased in time of high water to 3,500 cubic feet, and in time of low water may fall as low as 100 cubic feet or less.

As taking the water in the canal would destroy the power at the waterworks and Whiteside's mill, it is proposed to move the waterworks to the point of intake. This will necessitate laying about 4,000 feet of discharge main and the building of a new pump house. The

turbine and pump now in use could be moved. The present pump house is a brick structure about 15 feet square. The head now utilized at the pump house is 12 feet. The same head can be obtained where the river is taken into the canal. The supply can be taken from the river above the canal and the discharge main carried under, thus furnishing the same quantity and quality of water as they now have.

To do this, the two branches of the Chazy ought to be united above the canal and a dam about 200 feet in length and 5 feet in height founded on rock be built to turn the water through the pump house with a tailrace discharging into the canal. As the surface of the rock is at an elevation of about 160, no special construction is needed for receiving whatever water passes over the dam into the canal.

Whenever all the water is not used by the waterworks, the surplus belongs to Whiteside Brothers and has an available head of 20 feet.

Formerly this entire power was used to run a strawboard mill; but this has not been in operation since 1895, and since that date the right to use whatever water is needed has been transferred to the village of Champlain.

It is probable that 100 horsepower might be obtained from the surplus water for six or seven months in the year; but, as this would necessitate a steam plant of equal capacity for several months, it is doubtful if the surplus water has much commercial value.

About a mile farther down the stream there is another power. It would be necessary to return water to the streams above this dam equal to the amount taken in above. This can be easily done.

At the crossing of the Little Montreal River and Norton Creek the streams will have to be taken into the canal. As rock is found near the surface at both points, no receiving weirs will be needed. These streams will have to be carried across the canal in flumes and diverted during construction.

The bed of English River, where the canal crosses it, has an elevation of about 125. When gauged April 26, 1899, it was carrying 392 cubic feet per second. The maximum discharge may reach 1,000 cubic feet per second. As its elevation is above the bottom of the canal, to pass it under would require an inverted siphon, which would be not only expensive but objectionable on account of the heavy ice which forms in that region during the winter. For these reasons it was thought best to flood the valley above the canal and pass the water over a wasteweir. The area which would be flooded is about 1,000 acres. A wasteweir has been located at a point about three-fourths of a mile east of the river crossing. The water will be discharged into Norton Creek about a mile above its junction with the English River.

The wasteweir will be founded on rock at an elevation of 140.

The Chateauguay River is the largest stream crossed, and presents one of the most difficult problems on the line.

The following data in regard to the stream have been obtained:

| | |
|---|---|
| Above the dam at Ormstown: | |
| High water, April 11, 1887, in shoe store of W. Maw | 136.45 |
| Surface of water September 14, 1898 | 120.43 |
| Crest of dam, about | 120.00 |
| Below the dam: | |
| High water, April, 1887, on Murphy's home, 1½ miles below Ormstown | 136.00 |
| High water, April, 1899 | 119.00 |
| Surface of water September 14, 1898 | 110.14 |

On April 19, 1899, the river was carrying 2,720 cubic feet, with water surface at 113.29, 1½ miles below the dam.

I do not know of any high-water gauging. The maximum discharge may reach as high as 5,000 or 6,000 cubic feet per second.

Extreme high water is always caused by an ice gorge, which usually forms at the Grand Trunk Railway bridge, about 3 miles below town.

I have to suggest three methods of carrying the canal across the river:

First. By an aqueduct, the river being passed under the canal.

Second. By putting a dam across the river and flooding the valley above.

Third. By a dam and dikes on both sides to a point above the flowage line.

The various projects will now be considered.

First. To pass the river under the canal an aqueduct from 600 to 800 feet in length would be required. The conditions for this are not as favorable as could be desired. Low water in the river is about 110, ordinary high water 120, and extreme high water 136. The grade of bottom of canal with 30 feet of water is 122.4.

Owing to the large amount of ice which the river sometimes carries, the openings ought to be kept as large as possible; but on account of the great weight to be carried they ought to be of moderate spans. Spans of about 30 feet will probably best fulfill the conditions.

From the elevations given above it will be seen that there is very little headway, and at ordinary high water the crown of the arch will be submerged.

In order to give all the headway possible, the feasibility of carrying the aqueduct on steel girders with 30-foot span was considered. To do this with 24-inch I-beams weighing 80 pounds to the linear foot would require them to be spaced 10 inches between centers under the body of the aqueduct. As the side walls would weigh about two and one-half times as much as the water, the walls would have to be carried on deep girders built into the walls. As beams spaced 10 inches apart could not be painted, they would have to be encased in concrete to protect them. This leads at once to the Melan system of arches.

If arches were made 5 feet thick at the crown, which seems to be as much as is practicable under the circumstances, they would be lacking in strength to resist the pressure of the water tending to force the side walls of the aqueduct apart. This thrust for the 30-foot channel amounts to over 28,000 pounds per linear foot of the canal. As this force acts with a lever arm of 10 feet, there would be a moment of 280,000 foot-pounds for each linear foot of the aqueduct, tending to rupture the arch in a plane parallel to the axis of the aqueduct. A concrete arch under these conditions would not be stable. It would be necessary to strengthen the arches with steel rods or beams in a direction transverse to the axis of the aqueduct. Steel rods would probably also be required in the side walls to prevent cracks from temperature strains.

Ice forms in the streams in this region to a depth of 3 feet or more. It would undoubtedly form to a greater depth in the prism of the aqueduct and might rupture the walls unless the water was drawn off at the end of navigation. As the English River and other streams are to be taken in and discharged over wasteweirs, the entire canal can not be emptied. On this account gates will be necessary at both ends of the aqueduct, and a pipe with a gate carried through the wall to empty the water.

The ice which runs in the river passes over a dam about half a mile above our crossing, and would be pretty well broken up before reaching the aqueduct; but as an additional safeguard it would be well to put in masonry ice breakers a short distance above the aqueduct, spaced less than 30 feet apart, so that any ice which had passed them would pass through the openings in the aqueduct.

By doing this the ice would probably pass in safety at all ordinary times. There is, however, danger of an ice jam forming at the Grand Trunk Railway bridge, 3 miles below, and setting back to this point. In 1887, and again in 1888, this happened, and the water rose to a height of 136. This might cause an ice gorge above the aqueduct and raise the water still higher. If the aqueduct was filled it would be stable, even though the water went over the top of it; but any rise of water above that of 1887 would do serious damage to people in Ormstown and vicinity.

By adopting either the second or third plan proposed the danger from floods and ice would be lessened.

By putting a dam across the river above town and flooding the valley there would be submerged, as nearly as can be ascertained from data at hand, about 8,000 acres of land, which would probably be valued at from $75 to $100 per acre. In addition to this, the Grand Trunk Railway would have to be reconstructed for several miles.

By building dikes along both sides of the river to a point where there would be no danger of flowage, the stream could be taken in

and discharged over a waste weir with safety, and probably at no greater cost than for an aqueduct.[1]

For a 21-foot channel there would be no trouble in passing the river under the canal.

The line has been so located that by building the western end first and then changing the channel the whole aqueduct can be built in the dry.

*Siphons.*—There are several small brooks and ditches which cross the line at such an elevation that they will have to be passed under through inverted siphons. They will appear in the estimates.

*Discharge sluices.*—Discharge sluices ought to be built at the following points:

At lock east of Champlain, capable of discharging 4,000 cubic feet per second.

Between stations 9821 and 9791 of canal, one capable of passing 2,000 cubic feet per second.

At station 8666 of canal line, one to discharge not more than 3,000 cubic feet per second. This is to pass the water of English River. I doubt if it would be safe to discharge more at that point. It would be liable to flood the valley below.

*Railroad crossings.*—The following railroads are crossed: Delaware and Hudson, Ogdensburg and Lake Champlain, Hemmingford Branch of Grand Trunk, Canada Atlantic, Massena Branch of Grand Trunk, and St. Lawrence and Adirondack.

Estimates have been made for a change of location of the Delaware and Hudson, both branches of the Grand Trunk, and the Ogdensburg and Lake Champlain railways to secure crossings at right angles. All railway crossings are by means of swing bridges. The Canada Atlantic crosses the proposed canal at two points, and an estimate has been made of a new location of this road for a distance of about 9 miles to avoid any crossings.

All the embankments on these changes can be made from waste material from the canal excavation.

*Highway crossings.*—All highways have been estimated to be carried over on swing spans or fixed spans with a clear headway of 85

[1] After Mr. Davis had severed his connection with the Board, this subject was further considered and additional surveys made in October, 1899, by Mr. James J. Overn. This survey consisted of lines run along the high ground adjacent to both banks of the Chateauguay River from Huntingdon to Ormstown, and the information secured was sufficient to enable an estimate to be made of the embankments required by the third method mentioned above. This survey is not shown on the accompanying maps. The proposed location of the canal was changed, as shown on plates 45 and 46, in order that the dam might be located on rock foundation above the village of Ormstown. The estimated cost of the embankment is $405,000, and of the required right of way $117,000, making a total of $522,000. Method No. 3 is cheaper than No. 2 and avoids the uncertainties of the aqueduct plan. The location and estimates have been made in accordance with method No. 3 for both 21 and 30 foot channels.

feet, or by steam ferries, with pontoon bridges to be put across in place of the ferries during the period when the canal is not in operation. The ferries and pontoons would be not only much cheaper but less liable to any accident which would block the canal than swing bridges.

Ferry crossings have been estimated for the following points: At Cooperville, at Champlain, near Aubrey Station, at Fertile Creek road, at Ormstown.

Table No. 1 gives the location, length, cost, etc., of all railway and highway bridges estimated.

*Classification of excavation.*—The excavation can be classified under the following heads: Dredging, which would cover all materials which could best be removed with a dredge; earth excavation, covering all earth to be removed otherwise than by dredging; solid rock under water; solid rock above water.

All the excavation required in Lake Champlain will be dredging in earth. In Lake St. Francis there will be a small amount of rock.

*Character of materials.*—The earth is mostly a stiff clay. Between the following stations there will be found many bowlders: 9881 to 9241, 8941 to 8741, 7841 to 7721.

Between 9241 and 8941 there will be found a considerable amount of black muck. The depth is so very irregular that no attempt has been made to separate it from clay in the estimates.

I think most of the clay will stand at slopes of 2 to 1. However, there is some in the vicinity of the Chateauguay River and near the St. Louis River which may give trouble. Last spring some of this became almost like quicksand, the roads being absolutely impassable. On the Soulanges Canal there have been several bad slides on sections which have been excavated to the entire depth and left for two or more years without water being let in. I think the material at the Soulanges and near Ormstown is somewhat similar.

*Character of rock to be excavated.*—The surface rock appears to have been originally Utica shale, below which was limestone, changing almost imperceptibly into a calciferous sandstone, one of the Potsdam group, and finally into quartzite. Glacial action has worn this down so that the shale is only found along Lake Champlain and the Richelieu River. Near Champlain and Barrington limestone is found in limited quantities. Near Valleyfield the rock is usually limestone of such a quality that it is used for the manufacture of lime. Quartzite is found outcropping in every ledge of any importance along the line between Lake Champlain and Ormstown. It is safe to classify all this rock as hard sandstone or quartzite. Between Ormstown and Lake St. Francis the rock may be classified as limestone.

Samples from most of the ledges in the vicinity of the line are submitted.

The rock will all make excellent concrete, and enough building stone for most purposes can be found in the immediate vicinity of the line. At Champlain blocks 2 feet in thickness and 10 to 12 feet square can be quarried.

Photographs showing the stratification and seams in some of the ledges are given.

The quartzite occurs in strata varying from a few inches to several feet in thickness, and is broken up by many vertical seams. It can be channeled unless the vertical seams interfere.

*Ground water in cuts.*—As several of the borings develop flowing wells, I anticipate that much water will be found in the deep cuts.

*Sand.*—There is no good bank sand in the vicinity of the line. Sand for building purposes is found in both lakes, but what I saw was not of a first-rate quality. An excellent sand for concrete could be made by crushing quartzite.

*Details of alignment.*

| | | |
|---|---|---|
| Length of line from 30 feet of water in Lake Champlain to 30 feet in Lake St. Francis | miles | 53.674 |
| Distance between shores of lakes | do | 48.66 |
| Length of tangent | do | 38.49 |
| Total length of canal: | | |
| Radius 5,000 feet | feet | 15,567 |
| Radius 6,000 feet | do | 11,115 |
| Radius 7,000 feet | do | 13,175 |
| Radius 10,000 feet | do | 10,715 |
| Radius 12,000 feet | do | 12,700 |
| Radius 17,088 feet | do | 5,269 |
| Radius 10,111 feet | do | 11,634 |
| Total length of curve | miles | 15.18 |

*Character of channel.*

| | | |
|---|---|---|
| Earth, and earth with rock less than 5 feet above bottom | miles | 17.784 |
| Rock section | do | 30.871 |
| Lake section with dredging in bottom | do | 5.019 |

*Profile.*

| | |
|---|---|
| Proposed level of Lake Champlain | 100.00 |
| Proposed summit level | 152.40 |
| Lift of Lock No. 1 | 52.4 |
| Low water, Lake St. Francis | 150.89 |
| High water, Lake St. Francis | 155.81 |
| Extreme lift of guard lock | 3.4 |

Table No. 1 shows the location and cost of the proposed bridges; Table No. 2 shows the location and cost of the proposed locks; Table No. 3, detailed estimates of 30-foot channel; and Table No. 4, the estimate for 21-foot channel.

DODGE'S QUARRY, CHAMPLAIN, VT.

Upper 4 feet sandstone. Below that limestone.

QUARTZITE OUTCROP, 1 MILE WEST OF DODGE'S QUARRY.

QUARTZITE OUTCROP, 1 MILE SOUTH OF HOLTON STATION, P. Q.

QUARTZITE OUTCROP 1 MILE SOUTH OF HOLTON STATION, P. Q.

TABLE No. 1.—*Champlain route, northern division.*

BRIDGES.

| Location. | Station. | Kind of bridge. | Number of tracks. | Swing or fixed. | Number of spans. | 30-foot channel. Total length. | 30-foot channel. Estimated cost. | 21-foot channel. Total length. | 21-foot channel. Estimated cost. |
|---|---|---|---|---|---|---|---|---|---|
| | 7571 | Highway | ... | Swing.. | 1 | 235 | $19,986 | 195 | $16,650 |
| | 7674 | Railway | 1 | ....do.. | 1 | 537½ | 139,882 | 517½ | 118,772 |
| | 7770 | Highway | ... | ....do.. | 1 | 555 | 68,476 | 531 | 65,430 |
| Ormstown | 8071 | Railway | 1 | ....do.. | 1 | 537½ | 139,882 | 517½ | 118,772 |
| | 8923 | Highway | ... | ....do.. | 1 | 600 | 72,910 | 575 | 67,470 |
| | 9259 | Railway and highway.[1] | 1 | ....do.. | 3 | 600 | 217,730 | 576½ | 201,023 |
| | 9446 | Highway | ... | Fixed .. | 1 | 350 | 31,499 | 282 | 28,679 |
| | 9652 | ....do | ... | Swing.. | 1 | 570 | 69,572 | 546 | 65,683 |
| Champlain | 9752 | Railway | 1 | ....do.. | 1 | 564 | 112,838 | 540 | 103,810 |
| Cooperville | 10048 | ....do | 1 | ....do.. | 1 | 537½ | 111,536 | 517½ | 104,320 |
| *Bridges not over canal.* | | | | | | | | | |
| Ormstown | 8121 | Highway | ... | Fixed .. | 1 | 150 | 10,395 | 150 | 10,395 |
| | 8682 | ....do | ... | ....do.. | 1 | 100 | 8,350 | 100 | 8,350 |
| Dewittville | ..... | ....do | ... | ....do.. | ... | 120 | 9,893 | 120 | 9,893 |
| Above Ormstown | ..... | ..... | ... | ..... | ... | ..... | 5,000 | ..... | [2] 5,000 |
| Total | ..... | ..... | ... | ..... | ... | ..... | 1,017,949 | ..... | 920,247 |

[1] Double-deck drawspan, two 63-foot girders. [2] New abutments.

NOTE.—Highway bridge, 22 feet clear opening; single-track bridge, 14 feet clear opening; double-track bridge, 26 feet clear opening; single-track double-deck bridge, 26 feet clear opening.

TABLE No. 2.—*Champlain route, northern division.*

LOCKS.[1]

| No. | Station, upper end masonry. | Length of level. | Elevation, low-water surface. Above. | Elevation, low-water surface. Below. | Lift. | Remarks. |
|---|---|---|---|---|---|---|
| | | *Miles.* | | | | |
| 4 | 7566 | 39.0 | 152.4 | 152.4 | 00 | Guard lock at Valley Field. |
| 5 | 9876 | 43.7 | 152.4 | 100.0 | 52.4 | Champlain lock. |

[1] Lock at Lake Champlain regulating works is given in Appendix No. 8.

COST.

| Lock No. | 30-foot channel. | 21-foot channel. | Operating machinery. |
|---|---|---|---|
| 4 | $725,346 | $450,634 | $100,000 |
| 5 | 1,801,307 | 1,156,198 | 100,000 |
| | 2,526,653 | 1,606,832 | 200,000 |
| Operating machinery | 200,000 | 200,000 | ..... |
| Total | 2,726,653 | 1,806,832 | ..... |

TABLE No. 3.—*Champlain route, northern division.*

ESTIMATE OF COST OF CONSTRUCTION OF 30-FOOT CHANNEL.

Section No. 1, Station 7395 to 7532, Lake St. Francis:

| | |
|---|---|
| Excavation— | |
| Earth, wet, 2,755,626 cubic yards, at 15 cents | $413,344 |
| Rock, wet, 279,337 cubic yards, at $2.50 | 698,343 |
| Total | 1,111,687 |

| | |
|---|---|
| Section No. 2, Station 7532 to 9953, Lake St. Francis to Great Chazy River: | |
| Excavation— | |
| Earth, dry, 41,179,324 cubic yards, at 15 cents | $6,176,899 |
| Rock, dry, 57,724,771 cubic yards, at 65 cents | 37,521,101 |
| Embankment, excavation necessary furnished from canal prism, 9,133,645 cubic yards, at 15 cents | 1,370,047 |
| Embankment, Chateauguay River, required excavation not computed separately, 1,343,500 cubic yards, at 25 cents | 335,875 |
| Retaining wall, 437,384 cubic yards, at $4 | 1,749,536 |
| Slope wall, 501,528 square yards, at $1.10 | 551,681 |
| Back fill, 1,315,565 cubic yards, at 25 cents | 328,891 |
| Timber crib— | |
| Oak, 26,640 feet B. M., at $50 per M | 1,332 |
| Hemlock, 3,790,080 feet B. M., at $23 per M | 87,172 |
| Pine, 540,000 feet B. M., at $30 per M | 16,200 |
| Stone fill, 59,400 cubic yards, at 60 cents | 35,640 |
| Iron, 369,720 pounds, at 3 cents | 11,092 |
| Right of way— | |
| Town land, 27½ acres, at $1,500 | 41,250 |
| Farm land, 5,453 acres, at $91.50 | 497,440 |
| Farm land, Chateauguay, 1,170 acres, at $100 | 117,000 |
| Railroad changes, 14.07 miles | 218,599 |
| Entrance of streams— | |
| Excavation, rock, dry, 5,600 cubic yards, at 65 cents | 3,640 |
| Excavation, earth, dry, 186,700 cubic yards, at 15 cents | 28,005 |
| Gates (sluice and by-pass) | 26,970 |
| Bridges, 13 | 1,017,949 |
| Steam ferries, 5, at $20,000 | 100,000 |
| Lock No. 4, Valleyfield (guard lock) | 725,346 |
| Lock-operating machinery, 1 set single | 100,000 |
| Lock No. 5, Champlain | 1,801,307 |
| Lock-operating machinery, 1 set single | 100,000 |
| Dam at Ormstown— | |
| Concrete, 17,670 cubic yards, at $6 | 106,020 |
| Gate | 3,000 |
| Dam at Champlain, concrete, 1,315 cubic yards, at $6 | 7,890 |
| Champlain waterworks extension— | |
| Iron pipe, 2,471.5 tons, at $40 | 98,860 |
| Pump house | 500 |
| Total | 53,179,242 |
| Section No. 3, station 9953 to station 10101, Great Chazy River: | |
| Excavation— | |
| Earth, wet, 3,940,896 cubic yards, at 15 cents | 591,134 |
| Rock, wet, 1,048,571 cubic yards, at $2 | 2,097,142 |
| Right of way, farm land, 259 acres, at $100 | 25,900 |
| Total | 2,714,176 |
| Section No. 4, station 10101 to station 10231, Lake Champlain: | |
| Excavation— | |
| Earth, wet, 2,880,559 cubic yards, at 10 cents | 288,056 |
| Rock, wet, 2,631 cubic yards, at $2.50 | 6,578 |
| Total | 294,634 |
| Auxiliary work, Lake Champlain regulating works | 890,244 |

SUMMARY.

| Section. | Station to station. | Total cost. |
|---|---|---|
| 1 | 7395 7532 | $1,111,687 |
| 2 | 7532- 9953 | 53,179,242 |
| 3 | 9953- 10101 | 2,714,176 |
| 4 | 10101 10231 | 294,634 |
| Lake Champlain regulating works | | 890,244 |
| Total | | 58,189,983 |

TABLE No. 4.—*Champlain route, northern division.*

ESTIMATE OF COST OF CONSTRUCTION OF 21-FOOT CHANNEL.

| | |
|---|---|
| Section No. 1, station 7403 to station 7532, Lake St. Francis: | |
| Excavation— | |
| Earth, wet, 292,652 cubic yards, at 15 cents | $43,898 |
| Rock, wet, 74,041 cubic yards, at $2.50 | 185,103 |
| Total | 229,001 |
| Section No. 2, station 7532 to station 9953, Lake St. Francis to Great Chazy River: | |
| Excavation— | |
| Earth, dry, 34,767,719 cubic yards, at 15 cents | 5,215,158 |
| Rock, dry, 43,533,587 cubic yards, at 65 cents | 28,296,832 |
| Embankment— | |
| Excavation necessary furnished from canal prism, 9,540,775 cubic yards, at 15 cents | 1,431,116 |
| Chateauguay River, required excavation not computed separately, 1,343,500 cubic yards, at 25 cents | 335,875 |
| Retaining wall, 262,239 cubic yards, at $4 | 1,048,956 |
| Slope wall, 527,487 square yards, at $1.10 | 580,236 |
| Back fill, 699,974 cubic yards, at 25 cents | 174,994 |
| Timber crib— | |
| Oak, 26,640 feet B. M., at $50 per M | 1,332 |
| Hemlock, 2,764,080 feet B. M., at $23 per M | 63,574 |
| Pine, 540,000 feet B. M., at $30 per M | 16,200 |
| Stone fill, 43,200 cubic yards, at 60 cents | 25,920 |
| Iron, 273,600 pounds, at 3 cents | 8,208 |
| Right of way— | |
| Town land, 27½ acres, at $1,500 | 41,250 |
| Farm land, 5,453 acres, at $91.50 | 497,440 |
| Farm land, Chateauguay River, 1,170 acres, at $100 | 117,000 |
| Railroad changes, 14.07 miles | 218,599 |
| Entrance of streams— | |
| Excavation, rock, dry, 5,600 cubic yards, at 65 cents | 3,640 |
| Excavation, earth, 186,700 cubic yards, at 15 cents | 28,005 |
| Gates (sluice and by-pass) | 26,970 |
| Bridges, 13 | 920,247 |
| Steam ferries, 5, at $20,000 | 100,000 |
| Lock No. 4, Valleyfield (guard lock) | 450,634 |
| Lock-operating machinery, 1 set single lock | 100,000 |
| Lock No. 5, Champlain | 1,156,198 |
| Lock-operating machinery, 1 set single lock | 100,000 |

| | |
|---|---|
| Section No. 2, station 7532 to station 9953, Lake St. Francis to Great Chazy River—Continued. | |
| Dam at Ormstown— | |
| Concrete, 17,670 cubic yards, at $6 | $106,020 |
| Gate | 3,000 |
| Dam at Champlain, concrete, 1,315 cubic yards, at $6 | 7,890 |
| Champlain waterworks extension— | |
| Iron pipe, 2,471.5 tons, at $40 | 98,860 |
| Pump house | 500 |
| Total | 41,174,654 |
| Section No. 3, station 9953 to station 10101, Great Chazy River: | |
| Excavation— | |
| Earth, wet, 3,061,214 cubic yards, at 15 cents | 459,182 |
| Rock, wet, 336,535 cubic yards, at $2 | 673,070 |
| Right of way, farm land, 259 acres, at $100 | 25,900 |
| Total | 1,158,152 |
| Section No. 4, station 10101 to station 10171, Lake Champlain: | |
| Excavation, earth, wet, 1,049,293 cubic yards, at 10 cents | 104,929 |
| Auxiliary work, Lake Champlain regulating works | 890,244 |

SUMMARY.

| Section. | Station to station. | Total cost. |
|---|---|---|
| 1 | 7403–7532 | $229,001 |
| 2 | 7532–9953 | 41,174,654 |
| 3 | 9953–10101 | 1,158,152 |
| 4 | 10101–10171 | 104,929 |
| Lake Champlain regulating works | | 890,244 |
| Total | | 43,556,980 |

I wish to acknowledge the many courtesies which I received from the Canadian customs officials, who allowed free entry to all of our equipment without question or hindrance of any kind; also to the following gentlemen for valuable data furnished: Mr. J. W. Macklin, engineer of the Chambly Power Company, Montreal, Canada; Mr. Ernest Marceau, superintendent-engineer of railways and canals, Montreal, Canada; Mr. Thomas Monro, engineer of the Soulanges Canal, Coteau, Canada; Mr. J. F. Beique, superintendent of the Beauharnois Canal, Valleyfield, Canada; Mr. J. P. Benoit, superintendent of the Chambly Canal, Chambly, Canada; Capt. D. White, Rouse Point, N. Y.

The names of the assistants who filled the most important positions on this division are P. H. Ashmead, John J. L. Houston, V. W. Kline, M. G. Barnes, E. B. Wheeler, S. D. Woodward, instrument men; Charles G. Weyl, draftsman; Jason F. Stearns, superintendent of borings.

Very respectfully,

FRANK P. DAVIS,
*Assistant Engineer.*

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

APPENDIX NO. 13.

## OSWEGO-MOHAWK ROUTE, WESTERN DIVISION.

DETROIT, MICH., *September 30, 1899.*

GENTLEMEN: I have the honor to report as follows upon the western division of the Oswego-Mohawk route:

### GENERAL DESCRIPTION.

The Oswego route has been generally described as leaving Lake Ontario at Oswego, N. Y., following the Oswego River southward from the lake about 21.5 miles to Phoenix, then turning eastward to Oneida Lake, running across the lake to Wood Creek, along this creek to Rome, and down the Mohawk Valley from Rome to the Hudson River.

The portion of this route which has been designated as the western division extends from Oswego to Herkimer, a small village about 14 miles east of Utica, N. Y. It lies mostly in the counties of Oswego, Oneida, and Herkimer, but also passes through the northern part of Onondaga County. Oneida Lake is bordered on the southeast by Madison County.

The country traversed is thought to be the bed of an ancient lake, greater than and including Lake Ontario, whose outlet to the sea was through the Mohawk Valley. It is supposed that the region north of the Adirondacks was at that time covered by a field of ice and that the St. Lawrence River was yet unmade.

At a still earlier date this field of ice probably extended farther south, so as to cover the route described.[1]

In Oswego County the surface of the country is composed of a series of ridges and valleys extending in a southeasterly direction from Lake Ontario.

Oneida Lake is 125 feet above Lake Ontario and 371 feet above the sea. It is 21 miles long, averages about 4 miles in width, and receives the drainage from an area of about 1,348 square miles. It is bounded on the north by a strip of table-land, which separates it from Lake Ontario, and on the south by the Niagara escarpment. On the west an outlet is afforded by the Oneida River, which unites with the Seneca at Three River Point, 3 miles south of Phoenix, to form the Oswego River. On the east lies a level valley some 5 miles wide at the lake, but rising gradually and growing narrower as it approaches Rome. At Rome there is a low, short divide separating Wood Creek from the Mohawk. It is the highest land on the route, excepting Sand Ridge, and has an elevation of 430 feet above the sea. From Rome to Little Falls the river winds in a sinuous course along a narrow alluvial plain,

[1] See paper by G. K. Gilbert in Sixth Annual Report of the Commissioners of the New York State Reservation at Niagara.

and bears no resemblance to the rapidly descending and rocky channel below the falls.

The ridges in Oswego County are composed of gravel, sand, and clay in varying proportions and degrees of hardness. Rock does not generally appear in the ridges, and it is easy to think of them as the moraines of ancient glaciers, deposited upon the surface of the underlying rock. The comparatively recent formation of the topography is strikingly illustrated by the test borings made at Minetto, which show the bed rock to be higher in the river channel than beneath the hills on either side.

The argillaceous sandstone of the Utica formation is found in the river bed at Oswego. Between Oswego and Fulton is found the gray, brown, or mottled Medina sandstone, and between Fulton and Oneida Lake are found the Clinton shales. The material to be excavated in Oneida Lake is mostly soft mud. There is also a little sand and gravel, and near the outlet at Brewerton a small amount of rock was discovered.

East of Oneida Lake the rock encountered is a shale belonging to the Utica formation.

A few miles west of Rome there is a deposit of rock and hardpan, which separates the Wood Creek and Mohawk valleys. West of this ridge there is a deep deposit of sand and clay resting upon the Utica shale. East of Rome and along the Mohawk Valley there is a deep channel between the hills, filled in with sand, clay, and beds of gravel. This channel is somewhat tortuous, and in places spurs of rock jutting into the valley from the adjacent hills are intersected by the located canal channel.

The location and depth of proposed rock excavation can be readily seen on the profile of the line.

The country adjacent to the route is fertile and productive, but the route itself lies generally in swamps and water courses, which are of less value than ordinary farming land.

Building sand is abundant along the route. The sandstone at Oswego is unsuited for heavy masonry, but could be used for slope wall.

East of Oswego, at Chaumont, and north of Rome, on the Black River Canal, there exists an abundance of good limestone that could be brought to the route by water transportation. Granite is quarried on Grindstone Island, in the St. Lawrence, and is quite abundant on the islands at the head of the river.

The route appears to be well suited for the construction of a waterway of large dimensions. The vital question of water supply has been discussed elsewhere, and there remains but one feature concerning which any serious doubt need be expressed. Between Rome and Frankfort, in the Mohawk Valley, there is perhaps 10 miles of line along which much of the material to be excavated is loose sand and

clay, and the slopes of the channel would undoubtedly cause some trouble by caving into the canal. But such a condition means, at the worst, an increase of excavation that is small compared with the total, and its importance is not sufficient to weigh heavily against the route.

The particular line along this route which has been selected as best suited for the construction of a canal may be briefly described as follows:

The line leaves Lake Ontario about 1.1 miles west from the Oswego light-house, at a place known locally as Sheldons Point, and passes through the outskirts of the city along the westerly slope of a narrow valley. It crosses the Rome, Watertown and Ogdensburg Railroad tracks near that company's repair shops. The Delaware, Lackawanna and Western Railroad is intersected by it in the southwestern part of Oswego city, near the divide between the Oswego River and Lake Ontario, and it then follows the Delaware, Lackawanna and Western Railroad to the village of Minetto, where it enters the Oswego River, about 5.7 miles from its mouth.

From Minetto it follows the river about 4.9 miles, to the northern part of the village of Fulton. There it crosses the New York, Ontario and Western Railway and enters the valley of a small creek on the east side of the river. It passes up this creek, along the easterly side of Fulton, crosses the New York, Ontario and Western Railway again about four-fifths of a mile west of a flag station called Ingalls, and, continuing 3¼ miles farther, enters a swamp having an area of about 2¾ miles, and which is known as Peter Scott's Swamp. Up to this place the direction has been southeasterly. Here the course changes to easterly and crosses a glacial deposit called Sand Ridge, and the Oneida River, which skirts the ridge on the east. Then it crosses a second ridge and enters the Oneida River, the channel of which it follows about 1.7 miles, to the foot of Oneida Lake, at Brewerton.

The line passes through Oneida Lake a little north of its axis and enters Wood Creek Valley at Sylvan Beach, a summer resort on the eastern shore of the lake. About 5.5 miles from the lake the line begins to rise on the south side of the valley in order to pass over the Rome summit.

The Erie Canal is crossed about 3.4 miles west of Rome and again just east of that city. The New York Central and Hudson River Railroad and the New York, Ontario and Western Railway are crossed in the southern outskirts of the city; the New York Central and Hudson River Railroad is crossed a second time about 3 miles east of Rome, and the line passes down the valley, sometimes on one side and sometimes on the other. The Black River branch of the New York Central and Hudson River Railroad is crossed just west of Utica, and the main line is crossed again about 4.7 miles east of Utica. From there to Herkimer the valley is very narrow and is

already occupied by the New York Central and Hudson River Railroad and West Shore railroads. There is room between them for the canal, but there is no choice of location, and the present channel of the Mohawk must give place to that of the proposed waterway.

DETAILED DESCRIPTION AND ESTIMATES.

Estimates have been made for two channels having depths of 21 and 30 feet, respectively, and two radically different plans have been considered for passing the summit at Rome. The high-level plan is to pass over the summit with a minimum amount of excavation, to use a short high level at Rome, and to bring the water supply from the Black River Valley through a feeder 92.75 miles long. The survey and estimate for the feeder were not a part of the work of this division.

The low-level plan is to convert Oneida Lake into a great storage reservoir and excavate a channel through the Rome divide that would permit the waters of the lake to flow eastward into the Mohawk Valley.

This description is written chiefly with reference to a 30-foot channel on the high-level plan, but it applies generally to a 21-foot channel as well, and the portions of the route north of Fulton and east of Frankfort are common to both of the above-mentioned plans.

The elevation of water surface of the river level from Minetto to Fulton is determined by the crest of the lower Fulton dam. There are two dams at Fulton, which supply water to the Oswego Canal and to numerous mills and factories. It is considered that if either dam is to be affected by the proposed waterway it will be more economical to wipe out one dam entirely than to either partly submerge one or to wholly submerge one and part of the other.

As a general proposition, it is more economical to raise the water surface of a stream and buy the property submerged than to obtain the necessary depth of water by excavation.

With the water surface raised to the crest of the lower Fulton dam the submerged territory will include some low ground west of Minetto, a small cemetery just south of Minetto, a small amount of land along the river, a portion of the Black Creek Valley, the Battle Island dam, and the lower part of Fulton, which is thinly settled, but includes several shops and factories. Black Creek is a small stream which enters the river from the east about halfway between Minetto and Fulton, and Battle Island dam is located in the river just below the mouth of Black Creek. At present it is only used to furnish water to the Oswego Canal, but the right to the surplus waters for power purposes is held by private parties.

It is proposed to build a dam a little south of Minetto to raise the water to the desired elevation, and, by means of an embankment through the village and an excavated prism beyond, to extend the

same level northward across the summit between the river and the lake to the outskirts of Oswego, where the slope of the ground makes it necessary to lock down toward the lake.[1]

If the water surface were fixed at a lower elevation, there would be a great increase of rock excavation in the river channel and also in the earth excavation north of Minetto, the Fulton dam would be only partially submerged, and other conditions would not be varied enough to materially lessen the expense. If it were fixed at a higher elevation, the rock excavation in the river channel would not be materially lessened; the earth excavation in the canal prism north of Minetto would be lessened, but the Minetto embankment would be increased in height, which is objectionable; the additional property flooded in Fulton would be more valuable in proportion than that which it is proposed to submerge, and the head available for power at the upper Fulton dam would be lessened. These conditions were deemed sufficient to determine the elevation without making any comparative estimates.

The low-water elevation of Lake Ontario is 245.4, and the elevation proposed for the water surface of the river level is 331. The difference—85.6 feet—has been divided between four locks, each having a lift of 21.4 feet. The first is located on the shore of the lake, so as to save excavation by rising as quickly as possible above the lake level. The next two locks are combined in one structure, and located near the Rome, Watertown and Ogdensburg Railroad roundhouse, where there is a sudden rise of ground, which makes such an arrangement economical. The fourth lock is located in the southwestern part of the city of Oswego.[2]

The channel connecting the first lock with deep water in the lake is about 1,700 feet long and 600 feet wide. The material to be excavated is solid rock. Timber cribs have been planned for mooring vessels and guiding them into the lock, but the question of breakwaters to protect the entrance has not been considered in this report. That subject has been treated separately in Appendix No. 3. The design of locks Nos. 2 and 3 is such that the water may not always pass

[1] See footnote following for change of this proposed plan.

[2] After having been further considered by the Board, the location of the fourth lock has been changed since this report was completed. The new location is in the village of Minetto, a short distance below the proposed dam at this place. By the first location of the lock the canal would be carried through the village for a distance of about a mile between earth embankments having an average height of about 20 feet and a maximum height of 30 feet. The interests involved by the waterway itself and the village below the embankment, should a break occur in the same, have been deemed sufficient to warrant the change. With this location the entire canal section is below the surface of the ground. The adopted estimates have been changed accordingly, the increase in cost over the first location being, for the 30-foot channel, $1,190,413, and for the 21-foot channel $598,471. See plate 18 for this relocation.

through to the level below, as required, so sluice gates and a by-pass have been provided to feed water around the structure.

The dam at Minetto is 42 feet high above the river bed and 50 feet above the rock, and has a spillway 750 feet long. It is built of concrete and founded on solid rock, but the wings are anchored in banks of compact gravel and clay. While the construction of the wings would be less difficult and expensive if they could be built in rock, it is believed that they can be made perfectly secure in the existing material.

No guard lock has been planned where the canal leaves the river, because the fluctuation of flow in the Oswego River is not great, and can be provided for at a less cost by raising the lock walls at the lower end of the level and the canal banks through the village of Minetto.

The usual flood in the Oswego River is about 25,000 cubic feet per second; the maximum flood recorded is about 42,000 cubic feet per second. It is proposed at times to turn 10,000 cubic feet per second westward from the Mohawk into Oneida Lake. With a spillway 750 feet long, a flow of 52,000 cubic feet per second will produce a depth on its crest of about 8 feet. The lock walls at the lower end of the level and the slope walls along the level are planned 10 feet higher than the crest of the dam.[1]

But a flood of 10,000 cubic feet per second from the Mohawk would spread out over Oneida Lake and probably be exhausted before it could create a flow of 10,000 cubic feet per second in the Oneida and Oswego rivers. Moreover, to cause the maximum flood on the Oswego would require that a maximum flood should occur on the Seneca, the Oneida, and the Upper Mohawk simultaneously. Maximum floods usually occur when a warm rain falls on a layer of snow. It seldom happens that a heavy rain occurs on these three streams at once, and it is still more seldom that they are all covered with snow. If Oneida Lake is made a storage reservoir, the condition of a full reservoir would be added to those necessary for a maximum flood, and the probability of its occurrence would be still further lessened.

In the river level, where it is necessary to increase the depth by excavation, the submerged shoulders of the excavated prism would be invisible to navigators, and the river currents would make boats more difficult to guide than when in a regular canal prism. To lessen these difficulties the bottom width of the channel in the river has been made 400 feet instead of 203 feet or 250 feet, as shown in the regular canal sections.

The fifth lock is situated on Waterhouse Creek, in the northeastern part of Fulton, and has a lift of 22½ feet. The volume of excavation

[1] The results of the Cornell experiments, which have become available since Mr. Himes wrote his report, show that a coefficient of 4 may be used for ogee dams. Recomputing the height of high water over the Minetto dam, we obtain 6.7 instead of 8. This allows the height of lock walls and slope walls to be reduced 1 foot and also decreases the amount of territory estimated as flooded. (See also footnote on the preceding page.)

could be lessened and an equally good foundation secured by placing the lock nearer the river. The reason this was not done is because the canal prism above the lock would be excavated through beds of gravel so coarse and porous that it is doubtful whether it would hold water. A more thorough examination of the material might justify the location of the lock nearer the river, but it is safer with present information to base the estimate on the location selected.

The valley above lock No. 5 rises quite rapidly, and another lock, with a 22½-foot lift, is planned 1.193 miles farther along the line.

In locating the locks no attempt has been made to economize excavation by placing them so as to require earthen embankments to form the sides of the prism just above, it being considered that the interests which would justify the construction of so great a waterway should not be jeopardized by the use of earthen dams to retain 21 feet or 30 feet of water. Throughout the entire plan the water surface has been kept as near as practicable to the natural earth surface, and where embankments can not be avoided there is always a great surplus of excavation which may be used to give them an excess of strength.

Lock No. 6 raises the canal to the proposed low-water elevation of Oneida Lake, which is 376. The lake level is 40.833 miles long, and reaches from near Fulton across Oneida Lake and up the Wood Creek Valley 5.5 miles beyond Sylvan Beach. The line crosses the New York, Ontario, and Western Railway 1.4 miles beyond lock No. 6, near the summit of the divide between Waterhouse Creek and Peter Scott's swamp. The creek drains into the Oswego River, and the swamp drains into the Oneida River.

The surface of the swamp is about 12 feet lower than the canal water surface, and this is one of the few places where an embankment has been planned. The canal passes near the center of the swamp, where the earth is very soft to a depth of 70 feet, and the construction of an embankment upon it to hold 12 feet of water would be rather hazardous; but along the banks of the Oneida River, on the southern margin of the swamp, the earth is much firmer and the distance between high ground on either side is much shorter than along the line of the canal. It has therefore been planned to submerge the entire swamp by building an embankment along the river. Two small creeks run through the swamp into the river and should be cut off by dams before building the embankment.

The embankment is to be 10 feet higher than low-water surface in the lake and well lined with riprap. There is an abundance of clay and gravel with which to build it, and the great volume of material to be excavated in Sand Ridge on the east side of the swamp may be used to give it a cross section largely in excess of any possible requirement.

The deepest cut on the line is encountered in Sand Ridge, the maximum being about 84 feet.

At the crossing of the Oneida River on the east side of the ridge a weir has been planned to raise the water surface of the river and lake permanently to an elevation of 376, which is the highest known stage of the lake. It is proposed to build a timber structure,[1] with gates to be used when necessary, to maintain the low-water flow of the stream. The foundation, as shown by the nearest borings, is compact, gravelly earth.

To provide for evaporation and to maintain the present supply for power purposes at Phoenix and Fulton during the summer months, the crest of the weir is raised to 378, thus making a storage depth of 2 feet. The excess of evaporation over precipitation during navigation season will not exceed 16 inches,[2] and the balance, 8 inches, may be used for power purposes. The data to determine just how much water is needed to maintain the low-water flow of the stream are not available, but, when it is determined, the storage depth could be varied sufficiently to furnish the required amount without materially affecting the present estimate.

The crest of the weir is to be 800 feet long and will discharge a flow of 22,000 cubic feet per second with a depth of 4.1 feet on its crest.

The maximum flood in the Oswego River is about 42,000 cubic feet per second. The area of the watershed is 5,002 square miles, 10.6 per cent of which lies north of Three River Point. If we assume that the maximum flood at Three River Point is 42,000 cubic feet per second, and that it is divided between the Oneida and Seneca rivers in proportion to the areas of their respective watersheds, the flow from the Oneida is 12,000 cubic feet per second, and that from the Seneca is 30,000 cubic feet per second.

But in the Oneida basin the pondage area is 15.55 per cent of the total and in the Seneca basin the pondage area is 8.9 per cent of the total, so it is probable that the discharge of the Seneca would be the greater in proportion and that the flow assumed for the Oneida is excessive.

It has already been stated that in time of maximum flood it is intended to turn 10,000 cubic feet per second westward from the Mohawk, and the sum of the two volumes, 22,000 cubic feet per second, is the amount for which the weir is planned.

In the case[3] of ordinary floods there would be no flow from the Mohawk, and the Oswego flood of 25,000 cubic feet per second proportioned between the Seneca and Oneida rivers, as before, would produce a depth on the weir of 1.92 feet.[4]

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[1] In the finals this dam was estimated to be built of concrete.

[2] See low-level plan, water supply.

[3] See Report on Water Supply, Appendix No. 16.

[4] Since Mr. Himes's report was completed, the control of the Oneida River has been further considered by the Board, and the adopted estimates changed, as outlined below. By Mr. Himes's plan, flash boards or some form of movable dam would be required to raise the crest of the weir 2 feet at low water. It was thought that flash boards 2 feet high would hardly be in accordance with a work of this character. Since a movable dam must be built, a dam with 2-foot head

By this arrangement, if it should happen that an extreme flood occurred simultaneously in the Mohawk, Oneida, and Seneca rivers, the extra volume of 10,000 cubic feet per second from the Mohawk would make a higher flood than has yet occurred at Three River Point. Such a contingency is not likely to occur, but if it did, little damage would be done beyond the flooding of an increased area of farming land. Even this damage could be avoided by building a bear trap in the present Phoenix dam; but it is thought unnecessary and has not been included in the estimate.

A flood in the Oswego River below Phoenix, 10,000 cubic feet per second in excess of the maximum flood recorded, would probably do a little damage at Fulton. Below that, if the canal should follow the river to the lake, as described later, the increased section of waterway would carry the flood without difficulty. If the canal should leave the river at Minetto, as above described, an excessive flood would do some damage at Minetto and Oswego; but such a flood would occur so rarely, if at all, and the damage would be so small, that it would be cheaper to pay the damage than to provide works to avoid it.

The lowest stage of the water in Oneida Lake is probably 368.5, and the highest 376. No very valuable property would be injured by raising the water surface to 378, except at Sylvan Beach. There the ground is so low that practically the whole place would be destroyed. The tracks of the New York, Ontario and Western and the Lehigh Valley railroads, which cross the valley near Sylvan Beach would need to be raised a few feet and the embankments heavily riprapped.

The line adopted through the lake is that of least excavation. It has but two curves, one a little west of the center of the lake and the other at the entrance to the canal at the eastern end of the lake. A straight channel could be made through the lake at a somewhat greater expense for excavation; and in the case of a 21-foot channel the increased excavation would be so slight that the straight channel might be preferable to the one adopted.

The lake is less than 30 feet deep for a distance of 6.8 miles, measured from its western end. At the eastern end there is only one-half mile of water less than 30 feet deep. Where it is necessary to dredge a channel the proposed bottom width is 600 feet, so that open-water navigation will practically extend the whole length of the lake.

Here and in Peter Scott's swamp the material is so soft that the excavation has been estimated on slopes of 1 on 3 instead of 1 on 2, as shown on the standard cross section.

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would not cost materially less per linear foot than one with 5 feet of head. It is therefore proposed to reduce the length of weir to 300 feet and the elevation of crest of the fixed portion to 373. The movable portion of the dam is designed to raise the elevation of crest to 378. The sluice gates mentioned by Mr. Himes are designed for a high-water discharge of 10,000 cubic second-feet. This leaves 12,000 as the maximum discharge over the weir. Using 3.5 as the coefficient of discharge, the depth of flow on the fixed weir at high water would be 5.1, or the high-water elevation would be 378.1.

Fish Creek, which unites with Wood Creek just before it enters Oneida Lake, is a much larger stream than the latter and carries large volumes of silt into Oneida Lake. It is therefore impracticable to receive it into the canal, and an estimate has been made for a diversion channel to turn its waters into Oneida Lake, north of the canal entrance.

Two timber crib piers are provided at Sylvan Beach to prevent the loose sand on the shore from being washed into the channel.

At the west end of the lake the material is more compact and no such protection is required.

The next lock, which is the seventh from the beginning, is located at the first place east of the lake, where the ground is high and firm enough to build at a higher level and where a suitable lock foundation exists. The lock is a little south of Wood Creek and has a lift of 20 feet.

The eighth lock, which is the last of the ascending series, has also a lift of 20 feet, and is located 4.356 miles beyond Lock No. 7 and about 4 miles west from Rome. The water surface of the summit level has an elevation of 416 feet above the sea and 170.6 feet above low water in Lake Ontario.

The subject of floods on the Mohawk has been investigated by Mr. Rafter, and it is understood that a flow of 35,000 cubic feet per second at Little Falls can be taken safely down the river. It is to provide for the contingency of a greater flood that plans have been made to take 10,000 cubic feet per second westward from the summit level into Oneida Lake. To do this by-passes have been designed to convey the water around Locks Nos. 7 and 8, and the discharge through the passes would be controlled by gates, so that no water at all would go that way except when desired.

West of Rome the line crosses a wide plain through which it follows the line of greatest depression of the underlying rock. At Rome, where there is no rock, it passes through the southern outskirts of the city along the lowest ground between the Wood Creek and Mohawk basins.

From Rome eastward to the end of the division the Mohawk is too small to be considered in the location of the canal. The river is so crooked that it is frequently crossed by the canal, but the section of the latter is so much the greater, and near Rome its water surface is so much lower, that it would carry all the drainage and the river channel would be of no further use.

About a mile east of Rome, on the south side of the valley, the canal passes through a rock cut in which it is proposed to receive the water of the Mohawk. The channel is enlarged to lessen the disturbance that may be caused by the currents, and a basin and weir are planned to intercept the gravel and silt that may be borne down by the stream.

At Oriskany there is planned a weir and lock, having a lift of 20 feet. This lock is the first in the descending series east of Rome. Oriskany Creek is to be received into the pool above the weir, and will in no way affect the canal.

A similar weir and dam are planned at Frankfort, the lift being 20 feet as at Oriskany. The locations of both these locks are determined by the presence of rock that may serve as foundations.

The Frankfort lock is the tenth and last on the western division. The elevation of water surface below the lock is 376, the same as on Oneida Lake. Some additional work is required to collect the waters of the small streams between Rome and Frankfort and convey them to places where they can be received into the canal without injury to its slopes. This work has been included in the estimates.

In making the excavations between Rome and Frankfort, it will be necessary in those places where the material is very soft to carry it a considerable distance from the channel in order to prevent the superimposed weight from forcing in the banks of the canal.

With the exception of the Oneida River dam, all of the structures have foundations of solid rock. No borings have been made since the various structures have been located, save in the case of the upper lock at Fulton, and consequently it may be expected that a detailed examination of the lock sites might show an occasional slight change of location to be desirable, but the borings that were made are sufficient to show the presence of rock, so that the locations could be selected within narrow limits.

The estimates have been made according to standard plans and prices, which are fully described in the report of your Board, and need not be discussed here.

Table No. 1 gives the lengths of levels, lifts, and costs of the locks; Table No. 2 gives the location, kind, and cost of the bridges; Table No. 3 shows the alignment; Table No. 4 gives the different classes of navigation with the percentages of each, and Tables Nos. 5 and 6 give the total estimated costs of 21 and 30 foot channels, respectively. These six tables all pertain to the high-level plan.

TABLE NO. 1.—*Locks for high-level plan.*

| No. of lock. | Location of lock. | Single or double lock. | Elevation of low water. | | Lift, in feet. | Length of level, in miles. |
|---|---|---|---|---|---|---|
| | | | Below. | Above. | | |
| 1 | Oswego, N. Y | Single | 245.4 | 266.8 | 21.4 | |
| 2 and 3 | do | Double | 266.8 | 309.6 | 42.8 | 0.890 |
| 4 | Minetto, N. Y | Single | 309.6 | 331.0 | 21.4 | 4.384 |
| 5 | Fulton, N. Y | do | 331.0 | 353.5 | 22.5 | 5.900 |
| 6 | do | do | 353.5 | 376.0 | 22.5 | 1.193 |
| 7 | 6 miles east of Sylvan Beach | do | 376.0 | 396.0 | 20.0 | 40.833 |
| 8 | 4 miles west of Rome | do | 396.0 | 416.0 | 20.0 | 4.356 |
| 9 | Oriskany, N. Y | do | 396.0 | 416.0 | 20.0 | 13.648 |
| 10 | Frankfort, N. Y | do | 376.0 | 396.0 | 20.0 | 15.000 |
| | Head gates, lock 10, to end of division | | | | | 4.529 |
| | Total | | | | 210.5 | 90.733 |

TABLE NO. 1.—*Locks for high-level plain*—Continued.

COST.

| No. of lock. | 30-foot channel. | 21-foot channel. | Operating machinery, 30-foot and 21-foot channels. |
|---|---|---|---|
| 1 | $1,054,942 | $641,108 | $100,000 |
| 2 and 3 | 3,456,980 | 2,179,291 | 175,000 |
| 4 | 1,109,991 | 681,426 | 100,000 |
| 5 | 1,076,693 | 662,834 | 100,000 |
| 6 | 1,072,443 | 662,808 | 100,000 |
| 7 | 1,031,659 | 634,733 | 100,000 |
| 8 | 1,031,659 | 626,933 | 100,000 |
| 9 | 1,042,387 | 634,481 | 100,000 |
| 10 | 1,042,387 | 634,481 | 100,000 |
| | 11,919,141 | 7,358,095 | 975,000 |
| Operating machinery | 975,000 | 975,000 | ---------- |
| Total | 12,894,141 | 8,333,095 | ---------- |

NOTE.—In giving the lifts of locks no account is made of the fluctuations of water surfaces due to natural causes.

TABLE NO. 2.—*Bridges for high-level plan.*

| Location. | Station. | Kind of bridge. | Number of tracks. | Fixed or swing. | Number of spans. | 30-foot channel. | | 21-foot channel. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Total length. | Estimated cost. | Total length. | Estimated cost. |
| Oswego, N. Y | 15 | Highway | ------- | Swing | 1 | 545.0 | $68,240 | 525.0 | $66,796 |
| Do | 87 | Railway | 2 | do | 1 | 550.0 | 221,429 | 530.0 | 196,161 |
| Near Oswego, N. Y | 110 | Highway | ------- | do | 1 | 545.0 | 116,534 | 525.0 | 98,138 |
| Minetto, N. Y | 275 | do | ------- | do | 1 | 235.0 | 19,986 | 195.0 | 16,650 |
| Fulton, N. Y | 554 | Railway | 1 | do | 1 | 537.5 | 152,916 | 517.5 | 132,174 |
| Do | 582 | Highway | ------- | do | 1 | 235.0 | 19,986 | 195.0 | 16,650 |
| Caughnedoy, N. Y[1] | ------ | do | ------- | Fixed | 2 | 400.0 | 25,090 | 400.0 | 25,090 |
| Brewerton, N. Y | 1403 | Railway | 1 | Swing | 1 | 537.5 | 141,362 | 517.5 | 134,146 |
| Sylvan Beach, N. Y | 2550 | do | 1 | do | 1 | 537.5 | 141,184 | 517.5 | 125,796 |
| Rome, N. Y | 3292 | Highway | ------- | do | 1 | 545.0 | 95,456 | 525.0 | 80,820 |
| Do | 3304 | Railway | 1 | do | 1 | 537.5 | 142,548 | 517.5 | 117,236 |
| Utica, N. Y | 3995 | do | 1 | do | 1 | 537.5 | 137,444 | 517.5 | 117,236 |
| Do | 4038 | Highway | ------- | do | 1 | 545.0 | 95,456 | 525.0 | 80,820 |
| Near Utica, N. Y | 4236 | Railway | 2 | do | 1 | 550.0 | 221,429 | 530.0 | 196,161 |
| Do | 4242 | do | 2 | do | 1 | 550.0 | 221,429 | 530.0 | 196,161 |
| Frankfort, N. Y | 4555 | Highway | ------- | do | 1 | 235.0 | 19,986 | 195.0 | 16,650 |
| Ilion, N. Y | 4648 | do | ------- | do | 1 | 545.0 | 95,456 | 525.0 | 80,820 |
| Herkimer, N. Y | 4747 | do | ------- | do | 1 | 545.0 | 95,456 | 525.0 | 80,820 |
| Total | ------ | ---------- | ------- | ---------- | ------ | ------- | 2,031,387 | ------- | 1,782,500 |

[1] Not over channel.

TABLE NO. 3.—*High-level plan.*

| Length of tangent. | Length of curve. | Minimum radius of curvature. | Degree of curvature. | Percentage of tangent. | Percentage of curvature. |
|---|---|---|---|---|---|
| *Miles.* | *Miles.* | *Feet.* | ° ′ | | |
| 70,990 | 19,743 | 4,523.4 | 687 3¼ | 78.24 | 21.76 |

TABLE NO. 4.—*High-level plan.*

| | Miles. | Per cent. |
|---|---|---|
| Open water | 20.928 | 23.06 |
| Improved waterways | 4.962 | 5.47 |
| Canal prism | 64.843 | 71.47 |
| Total | 90.733 | 100.00 |

TABLE NO. 5.—*Estimate—Oswego-Mohawk route, western division.*

HIGH-LEVEL PLAN—30-FOOT CHANNEL.

| | |
|---|---|
| **Lake Ontario section (station −26 + 00 to −9 + 20):** | |
| Excavation— | |
| Submerged rock, 349,670 cubic yards, at $2 | $699,340 |
| Breakwater (Appendix No. 3) | 1,190,317 |
| Crib work— | |
| Pine, 2,415,600 feet B. M., at $30 per M | 72,468 |
| Hemlock, 5,840,620 feet B. M., at $23 per M | 134,334 |
| Oak, 97,920 feet B. M., at $50 per M | 4,896 |
| Iron, 742,870 pounds, at 3 cents | 22,286 |
| Stone fill, 102,034 cubic yards, at 60 cents | 61,220 |
| Total | 2,184,861 |
| **Oswego-Minetto section (station −9 + 20 to 288 + 00):** | |
| Excavation— | |
| Earth, dry, 11,866,321 cubic yards, at 20 cents | 2,373,264 |
| Rock, dry, 1,969,596 cubic yards, at 65 cents | 1,280,237 |
| Retaining wall, 143,479 cubic yards, at $4 | 573,916 |
| Masonry in by-passes, 4,300 cubic yards, at $4 | 17,200 |
| Slope wall, 68,448 square yards, at $1.10 | 75,293 |
| Back fill, 449,336 cubic yards, at 25 cents | 112,334 |
| Crib work— | |
| Pine, 2,374,400 feet B. M., at $30 per M | 71,232 |
| Hemlock, 6,992,000 feet B. M., at $23 per M | 160,816 |
| Oak, 96,920 feet B. M., at $25 per M | 2,423 |
| Iron, 786,632 pounds, at 3 cents | 23,599 |
| Stone fill, 125,856 cubic yards, at 60 cents | 75,514 |
| Railroad and highway changes | 29,660 |
| Locks— | |
| No. 1 | 1,054,942 |
| Nos. 2 and 3 | 3,456,980 |
| No. 4 | 1,109,991 |
| Lock-operating machinery— | |
| 2 sets single, at $100,000 | 200,000 |
| 1 set double, at $175,000 | 175,000 |
| Bridges | 426,189 |
| Right of way— | |
| City property, 277 acres, at $2,080 | 576,160 |
| Farm land, 729 acres, at $200 | 145,800 |
| Total | 11,940,550 |
| **Minetto-Fulton section (stations 288+00 to 550+00):** | |
| Excavation— | |
| Earth, 1,911,170 cubic yards, at 18 cents | 344,011 |
| Rock, dry, 117,268 cubic yards, at 65 cents | 76,224 |
| Slope wall, 14,508 square yards, at $1.10 | 15,959 |
| Minetto dam (No. 1)— | |
| Excavation, 25,567 cubic yards, at 20 cents | 5,113 |
| Masonry in dam and abutments, 44,913 cubic yards, at $6 | 269,478 |
| Cofferdams, estimated cost | 55,000 |
| Railroad and highway changes | 25,670 |

| | |
|---|---|
| Minetto-Fulton section—Continued. | |
| Right of way: | |
| Farm land, 1,154 acres, at $100 | $115,400 |
| Swamp land, 408 acres, at $12.50 | 5,100 |
| Water rights, Battle Island dam | 150,000 |
| Total | 1,061,955 |
| Fulton-Brewerton section (stations 550 + 00 to 1410 + 00): | |
| Excavation— | |
| Earth, dry, 29,190,187 cubic yards, at 18 cents | 5,254,234 |
| Rock, dry, 2,047,113 cubic yards, at 65 cents | 1,330,623 |
| Dike in Peter Scott's swamp: | |
| Excavation, 383,000 cubic yards, at 18 cents | 68,940 |
| Embankment, 588,000 cubic yards, at 25 cents | 147,000 |
| Riprap, 71,000 cubic yards, at 90 cents | 63,900 |
| Retaining wall, 129,353 cubic yards, at $4 | 517,412 |
| Slope wall, 201,946 square yards, at $1.10 | 222,141 |
| Back fill, 548,894 cubic yards, at 25 cents | 137,224 |
| Crib work— | |
| Pine, 1,903,200 feet B. M., at $30 per M | 57,096 |
| Hemlock, 7,423,680 feet B. M., at $23 per M | 170,745 |
| Oak, 52,560 feet B. M., at $50 per M | 2,628 |
| Iron, 788,404 pounds, at 3 cents | 23,652 |
| Stone, 125,172 cubic yards, at 60 cents | 75,103 |
| Oneida River dam (No. 2)— | |
| Excavation, 14,000 cubic yards, at 18 cents | 2,520 |
| Embankment, 43,700 cubic yards, at 15 cents | 6,555 |
| Masonry in dam and abutments, 6,018 cubic yards, at $6 | 36,108 |
| Two Stoney gates to discharge 10,000 cubic feet per second | 46,250 |
| Movable dam, 5 feet high, 300 feet long, at $9.40 per linear foot | 2,820 |
| Operating machinery | 1,000 |
| Railroad and highway changes | 73,400 |
| Steam ferries, 4, at $20,000 | 80,000 |
| Locks— | |
| No. 5 | 1,076,693 |
| No. 6 | 1,072,443 |
| Lock-operating machinery, 2 sets single, at $100,000 | 200,000 |
| Bridges | 339,354 |
| Right of way— | |
| Village property, Fulton, N. Y., 55 acres, at $2,600 | 143,000 |
| Farm land, 5,910 acres, at $100 | 591,000 |
| Swamp land, 2,446 acres, at $12.50 | 30,575 |
| Water rights, Fulton, N. Y. | 806,000 |
| Total | 12,578,416 |
| Brewerton to lock No. 7 section (station 1410 + 00 to 2782 + 00): | |
| Excavation— | |
| Earth, 15,736,440 cubic yards, at 8 cents | 1,258,915 |
| Rock, wet, 719,100 cubic yards, at $2 | 1,438,200 |
| Fish Creek diversion, earth, 308,000 cubic yards, at 8 cents | 24,640 |
| Slope wall, 94,746 square yards, at $1.10 | 104,221 |

| | |
|---|---|
| **Brewerton to lock No. 7 section, etc.—Continued.** | |
| Crib work— | |
| Pine, 1,560,000 feet B. M., at $30 per M | $46,800 |
| Hemlock, 5,769,100 feet B. M., at $23 per M | 132,689 |
| Oak, 43,560 feet B. M., at $50 per M | 2,178 |
| Iron, 616,342 pounds, at 3 cents | 18,490 |
| Stone fill, 97,566 cubic yards, at 60 cents | 58,540 |
| Railroad and highway changes | 112.638 |
| Bridges | 141,184 |
| Right of way— | |
| Farm land, 10,541 acres, at $100 | 1,054,100 |
| Swamp land, 4,800 acres, at $12.50 | 60,000 |
| Village property, Sylvan Beach | 109,000 |
| Total | 4,561,595 |
| **Lock No. 7, Fort Bull section (station 2782+00 to 3164+00):** | |
| Excavation— | |
| Earth, 15,702,581 cubic yards, at 20 cents | 3,140,516 |
| Rock, dry, 257,522 cubic yards, at 70 cents | 180,265 |
| Retaining wall, 47,330 cubic yards, at $4 | 189,320 |
| Masonry in by-pass, 10,000 cubic yards, at $4 | 40,000 |
| Slope wall, 100,467 square yards, at $1.10 | 110,514 |
| Back fill, 425,084 cubic yards, at 25 cents | 106,271 |
| Crib work— | |
| Pine, 2,854,800 feet B. M., at $30 per M | 85,644 |
| Hemlock, 10,897,220 feet B. M., at $23 per M | 250,636 |
| Oak, 78,840 feet B. M., at $50 per M | 3,942 |
| Iron, 1,160,606 pounds, at 3 cents | 34,818 |
| Stone fill, 184,098 cubic yards, at 60 cents | 110,459 |
| Highway changes | 680 |
| Steam ferry, 1 | 20.000 |
| Locks— | |
| No. 7 | 1,031.659 |
| No. 8 | 1,031,659 |
| Lock-operating machinery, 2 sets single, at $100,000 | 200,000 |
| Right of way— | |
| Farm land, 943 acres, at $100 | 94,300 |
| Total | 6,630,683 |
| **Fort Bull—Herkimer section (station 3164 + 00 to 4789 + 91.5):** | |
| Excavation— | |
| Earth, 61,434,573 cubic yards, at 18 cents | 11,058,223 |
| Rock, dry, 494,380 cubic yards, at 70 cents | 346,066 |
| Retaining wall, 73,685 cubic yards, at $4 | 294,740 |
| Masonry in by-passes, receivers, etc., 27,400 cubic yards, at $4 | 109,600 |
| Slope wall, 841,185 square yards, at $1.10 | 925,303 |
| Back fill, 378,858 cubic yards, at 25 cents | 94,715 |
| Crib work— | |
| Pine, 2,277,600 feet B. M., at $30 per M | 68,328 |
| Hemlock, 8,832,200 feet B. M., at $23 per M | 203,141 |
| Oak, 62,880 feet B. M., at $50 per M | 3,144 |
| Iron, 964,024 pounds, at 3 cents | 28,921 |
| Stone fill, 143,297 cubic yards, at 60 cents | 85,978 |

| | |
|---|---|
| Fort Bull—Herkimer section, etc.—Continued. | |
| Dams— | |
| Oriskany, N. Y. (No. 3)— | |
| Excavation, 787,000 cubic yards, at 18 cents | $141,660 |
| Masonry in dams and abutments, 21,835 cubic yards, at $6 | 131,010 |
| Timber in grillage foundation, 1,101,372 feet B. M., at $22 per M | 24,230 |
| Piles in foundation, 155,100 linear feet, at 20 cents | 31,020 |
| Sheet piling, 128,000 feet B. M., at $33 per M | 4,224 |
| Iron, 80,000 pounds, at 3 cents | 2,400 |
| Stoney gate to discharge 500 cubic feet per second | 2,000 |
| Frankfort, N. Y. (No. 4)— | |
| Excavation, 639,000 cubic yards, at 18 cents | 115,020 |
| Masonry in dam and abutments, 21,835 cubic yards, at $6 | 131,010 |
| Timber in grillage foundation, 1,101,372 feet B. M., at $22 per M | 24,230 |
| Piles in foundation, 155,100 linear feet, at 20 cents | 31,020 |
| Sheet piling, 128,000 feet B. M., at $33 per M | 4,224 |
| Iron, 80,000 pounds, at 3 cents | 2,400 |
| Railroad and highway changes | 450,170 |
| Steam ferry, 1 | 20,000 |
| Locks— | |
| No. 9 | 1,042,387 |
| No. 10 | 1,042,387 |
| Lock-operating machinery, 2 sets single, at $100,000 | 200,000 |
| Bridges | 1,124,660 |
| Right of way— | |
| Farm land, 10,335 acres, at $100 | 1,033,500 |
| Total | 18,775,711 |

TOTAL COST.

| | |
|---|---|
| Lake Ontario section | $2,184,861 |
| Oswego-Minetto section | 11,940,550 |
| Minetto-Fulton section | 1,061,955 |
| Fulton-Brewerton section | 12,578,416 |
| Brewerton-Lock No. 7 section | 4,561,595 |
| Lock No. 7-Fort Bull section | 6,630,683 |
| Fort Bull-Herkimer section | 18,775,711 |
| Water Supply, Appendix No. 16 | 18,080,752 |
| Total | 75,814,523 |

TABLE NO. 6.—*Estimate—Oswego-Mohawk route, western division.*

HIGH LEVEL PLAN—21-FOOT CHANNEL.

| | |
|---|---|
| Lake Ontario section (station −20+00 to −9+20): | |
| Excavation— | |
| Submerged rock, 152,361 cubic yards, at $2 | $304,722 |
| Breakwater, Appendix No. 3 | 721,380 |
| Crib work— | |
| Pine, 2,416,000 feet B. M., at $30 per M | 72,480 |
| Hemlock, 3,096,800 feet B. M., at $23 per M | 71,226 |
| Oak, 83,600 feet B. M., at $50 per M | 4,180 |
| Iron, 490,585 pounds, at 3 cents | 14,718 |
| Stone fill, 63,325 cubic yards, at 60 cents | 37,995 |
| Total | 1,226,701 |

| | |
|---|---|
| Oswego-Minetto section (station −9+20 to 288+00): | |
| Excavation— | |
| Earth, dry, 9,300,777 cubic yards, at 20 cents | $1,860,155 |
| Rock, dry, 843,884 cubic yards, at 65 cents | 548,525 |
| Retaining wall, 97,906 cubic yards, at $4 | 391,624 |
| Masonry in by-passes, 4,300 cubic yards, at $4 | 17,200 |
| Slope wall, 88,288 square yards, at $1.10 | 97,117 |
| Back fill, 348,900 cubic yards, at 25 cents | 87,225 |
| Crib work— | |
| Pine, 2,374,400 feet B. M., at $30 per M | 71,232 |
| Hemlock, 4,893,400 feet B. M., at $23 per M | 112,571 |
| Oak, 53,760 feet B. M., at $50 per M | 2,688 |
| Iron, 593,600 pounds, at 3 cents | 17,808 |
| Stone fill, 94,576 cubic yards, at 60 cents | 56,746 |
| Railroad and highway changes | 29,660 |
| Locks— | |
| No. 1 | 641,108 |
| Nos. 2 and 3 | 2,179,291 |
| No. 4 | 681,426 |
| Lock-operating machinery— | |
| 2 sets single, at $100,000 | 200,000 |
| 1 set double, at $175,000 | 175,000 |
| Bridges | 377,745 |
| Right of way— | |
| City property, 277 acres, at $2,080 | 576,160 |
| Farm land, 729 acres, at $200 | 145,800 |
| Total | 8,269,081 |
| Minetto-Fulton section (station 288—00 to 550—00): | |
| Excavation— | |
| Earth, 914,740 cubic yards, at 18 cents | 164,653 |
| Slope wall, 13,414 square yards, at $1.10 | 14,755 |
| Minetto Dam (No. 1)— | |
| Excavation, 25,567 cubic yards, at 20 cents | 5,113 |
| Masonry in dam and abutments, 44,913 cubic yards, at $6 | 269,478 |
| Cofferdams | 55,000 |
| Railroad and highway changes | 25,670 |
| Right of way— | |
| Water rights, Battle Island Dam | 150,000 |
| Farm land, 1,154 acres, at $100 | 115,400 |
| Swamp land, 408 acres, at $12.50 | 5,100 |
| Total | 805,169 |
| Fulton-Brewerton section (station 550—00 to 1410—00): | |
| Excavation— | |
| Earth, 21,192,092 cubic yards, at 18 cents | 3,814,576 |
| Rock, dry, 941,910 cubic yards, at 65 cents | 612,241 |
| Peter Scott's Swamp Dike— | |
| Excavation, 383,000 cubic yards, at 18 cents | 68,940 |
| Embankment, 588,000 cubic yards, at 25 cents | 147,000 |
| Riprap, 71,000 cubic yards, at 90 cents | 63,900 |
| Retaining wall, 71,756 cubic yards, at $4 | 287,024 |
| Slope wall, 196,551 square yards, at $1.10 | 216,206 |
| Back fill, 356,371 cubic yards, at 25 cents | 89,093 |

| | |
|---|---|
| Fulton-Brewerton section, etc.—Continued. | |
| Crib work— | |
| Pine, 2,449,200 feet B. M., at $30 per M | $73,476 |
| Hemlock, 6,836,300 feet B. M., at $23 per M | 157,235 |
| Oak, 70,200 feet B. M., at $50 per M | 3,510 |
| Iron, 776,277 pounds, at 3 cents | 23,288 |
| Stone fill, 120,978 cubic yards, at 60 cents | 72,587 |
| Oneida River Dam (No. 2)— | |
| Excavation, 14,000 cubic yards, at 18 cents | 2,520 |
| Embankment, 43,700 cubic yards, at 15 cents | 6,555 |
| Masonry in dam and abutments, 6,018 cubic yards, at $6 | 36,108 |
| Two gates (Stoney to discharge 10,000 cubic feet per second) | 46,250 |
| Movable dam 5 feet high, 300 feet long, at $9.40 per linear foot | 2,820 |
| Operating machinery | 1,000 |
| Railroad and highway changes | 73,400 |
| Steam ferries, 4, at $20,000 | 80,000 |
| Locks— | |
| No. 5 | 662,834 |
| No. 6 | 662,808 |
| Lock-operating machinery— | |
| Two sets single | 200,000 |
| Bridges | 308,030 |
| Right of way— | |
| Village property, Fulton, N. Y., 55 acres, at $2,600 | 143,000 |
| Farm land, 5,910 acres, at $100 | 591,000 |
| Swamp land, 2,446 acres, at $12.50 | 30,575 |
| Water rights, Fulton, N. Y | 806,000 |
| Total | 9,282,006 |
| Brewerton—Lock No. 7 section (station 1410+00 to 2782+00): | |
| Excavation— | |
| Earth, 8,089,246 cubic yards, at 8 cents | 647,140 |
| Rock, wet, 171,046 cubic yards, at $2 | 342,092 |
| Fish Creek diversion— | |
| Excavation, earth, 308,000 cubic yards, at 8 cents | 24,640 |
| Slope wall, 108,540 square yards, at $1.10 | 119,394 |
| Crib work— | |
| Pine, 1,210,000 feet B. M., at $30 per M | 36,300 |
| Hemlock, 3,483,760 feet B. M., at $23 per M | 80,126 |
| Oak, 31,680 feet B. M., at $50 per M | 1,584 |
| Iron, 366,080 pounds, at 3 cents | 10,982 |
| Stone fill, 56,760 cubic yards, at 60 cents | 34,056 |
| Railroad and highway changes | 112,638 |
| Bridges | 125,796 |
| Right of way— | |
| Farm land, 10,541 acres, at $100 | 1,054,100 |
| Village property, Sylvan Beach | 109,000 |
| Swamp land, 4,800 acres, at $12.50 | 60,000 |
| Total | 2,757,848 |
| Lock No. 7, Fort Bull section (station 2782+00 to 3164+00): | |
| Excavation— | |
| Earth, 12,145,959 cubic yards, at 20 cents | 2,429,192 |
| Rock, dry, 33,420 cubic yards, at 70 cents | 23,394 |

| | |
|---|---|
| Lock No. 7, Fort Bull section, etc.—Continued. | |
| Masonry in by-pass, 10,000 cubic yards, at $4 | $40,000 |
| Slope wall, 161,784 square yards, at $1.10 | 177,962 |
| Back fill, 281,840 cubic yards, at 25 cents | 70,460 |
| Crib work— | |
| Pine, 3,806,400 feet B. M., at $30 per M | 114,192 |
| Hemlock, 10,191,600 feet B. M., at $23 per M | 234,407 |
| Oak, 105,120 feet B. M., at $50 per M | 5,256 |
| Iron, 1,165,448 pounds, at 3 cents | 34,963 |
| Stone fill, 181,536 cubic yards, at 60 cents | 108,922 |
| Highway changes | 680 |
| Steam ferry, 1 | 20,000 |
| Locks— | |
| No. 7 | 634,733 |
| No. 8 | 626,933 |
| Lock-operating machinery— | |
| Two sets single, at $100,000 | 200,000 |
| Right of way— | |
| Farm land, 943 acres, at $100 | 94,300 |
| Total | 4,815,394 |
| Fort Bull-Herkimer section (station 3164 + 00 to 4789 + 91.5): | |
| Excavation— | |
| Earth, 45,963,879 cubic yards, at 18 cents | 8,273,498 |
| Rock, dry, 85,828 cubic yards, at 70 cents | 60,080 |
| Masonry in receivers and by-pass, 27,400 cubic yards, at $4 | 109,600 |
| Slope wall, 790,867 square yards, at $1.10 | 869,954 |
| Back fill, 247,120 cubic yards, at 25 cents | 61,780 |
| Crib work— | |
| Pine, 3,806,400 feet B. M., at $30 per M | 114,192 |
| Hemlock, 10,677,600 feet B. M., at $23 per M | 245,585 |
| Oak, 105,120 feet B. M., at $50 per M | 5,256 |
| Iron, 1,244,488 pounds, at 3 cents | 37,335 |
| Stone, 180,016 cubic yards, at 60 cents | 108,010 |
| Dams— | |
| Oriskany, N. Y. (No. 3): | |
| Excavation, 787,000 cubic yards, at 18 cents | 141,660 |
| Masonry in dam and abutments, 21,835 cubic yards, at $6 | 131,010 |
| Timber in grillage foundation, 1,101,372 feet B. M., at $22 per M | 24,230 |
| Piles in foundation, 155,100 linear feet, at 20 cents | 31,020 |
| Sheet piling, 128,000 feet B. M., at $33 per M | 4,224 |
| Iron, 80,000 pounds, at 3 cents | 2,400 |
| Stoney gate to discharge 500 cubic feet per second | 2,000 |
| Frankfort, N. Y. (No. 4): | |
| Excavation, 639,000 cubic yards, at 18 cents | 115,020 |
| Masonry in dam and abutments, 21,835 cubic yards, at $6 | 131,010 |
| Timber in grillage foundation, 1,101,372 feet B. M., at $22 per M | 24,230 |
| Piles in foundation, 155,100 linear feet, at 20 cents | 31,020 |
| Sheet piling, 128,000 feet B. M., at $33 per M | 4,224 |
| Iron, 80,000 pounds, at 3 cents | 2,400 |
| Railroad and highway changes | 450,170 |
| Steam ferry, 1 | 20,000 |

| | |
|---|---|
| Fort Bull-Herkimer section, etc.—Continued. | |
| Locks— | |
| No. 9 | $634,481 |
| No. 10 | 634,481 |
| Lock-operating machinery— | |
| 2 sets single, at $100,000 | 200,000 |
| Bridges | 966,724 |
| Right of way— | |
| Farm land, 10,335 acres at $100 | 1,033,500 |
| Total | 14,469,094 |

TOTAL COST.

| | |
|---|---|
| Lake Ontario section | $1,226,701 |
| Oswego-Minetto section | 8,269,081 |
| Minetto-Fulton section | 805,169 |
| Fulton-Brewerton section | 9,282,006 |
| Brewerton-Lock No. 7 section | 2,757,848 |
| Lock No. 7-Fort Bull section | 4,815,394 |
| Fort Bull-Herkimer section | 14,469,094 |
| Water supply, Appendix No. 16 | 18,080,752 |
| Total | 59,706,045 |

ALTERNATIVE ROUTES AND PLANS.

*Minnetto to Oswego.*—It was at first proposed to enter the river directly from the lake at Oswego, to excavate a channel as far as the present Oswego dam, and build there a dam and lock which would raise the water surface 30.6 feet above low water in the lake; to build another dam and lock having a lift of 30 feet about three-fourths of a mile farther up the river, and a third lock near Minetto, having a lift of 25 feet, which would raise the water surface to 331, the elevation of the crest of the proposed Minetto dam, which has already been described. The last lock was located at the north end of a small valley lying on the east side of the ridge against which the east end of the proposed Minetto dam abuts, and which is known as Seneca Hill. Above the lock the canal was to pass through the valley in a southerly direction and enter the river again 1¼ miles beyond the lock. The use of this valley would avoid a rather sharp bend in the river and permit the location of the lock considerably farther downstream than would otherwise be practicable, thus escaping a large amount of rock excavation in the river bed.

The locks and dams were all so located as to be constructed readily and have good rock foundations. The river banks at the dam sites are composed of rock, which would afford secure abutments for the dams.

The comparative estimate given below shows that the cost for excavation alone on the line adopted is, for a 30-foot channel, $865,097 less than on the river line:

TABLE NO. 7.—*Comparative estimate for excavation for 30-foot channels between Minetto and Lake Ontario.*

ADOPTED LINE.[1]

| | |
|---|---|
| Earth excavation, 12,080,380 cubic yards, at 20 cents | $2,416,076 |
| Submerged rock excavation in Lake Ontario, 349,670 cubic yards, at $2 | 699,340 |
| All other rock excavation, 1,969,596 cubic yards, at 65 cents | 1,280,237 |
| Total | 4,395,653 |

RIVER LINE.

| | |
|---|---|
| Gravel dredging in Lake Ontario, 491,000 cubic yards, at 20 cents | $98,200 |
| Earth excavation along Oswego River, 3,709,000 cubic yards, at 20 cents | 741,800 |
| Submerged rock excavation in Oswego River, 929,000 cubic yards, at $2 | 1,858,000 |
| Rock excavation along Oswego River, 1,991,000 cubic yards, at $1.25 | 2,488,750 |
| Removal of old cribs, 36,000 cubic yards, at $1 | 36,000 |
| Removal of old masonry, 38,000 cubic yards, at $1 | 38,000 |
| Total | 5,260,750 |
| Cost of excavation on adopted line[2] | 4,395,653 |
| Difference of cost in favor of adopted line[2] | 865,097 |

This difference in cost may be partly explained by saying that where the proposed channel follows the river its estimated bottom width is 400 feet instead of 203 feet or 250 feet, the width of base used for earth and rock respectively in the regular canal prism, and also that because of the valuable property along the river banks it is impracticable to build a dam and raise the water surface within 1¼ miles of the lake, and it therefore would be necessary to excavate a very large volume of rock under water, an expensive class of work, which is largely avoided on the other line.[3]

There are, however, other and more important advantages in favor of the adopted line, which will be briefly mentioned.

On the river line two masonry dams would be needed between Minetto and Oswego. In addition to the expense of these structures the present Minetto dam and the dam midway between Oswego and Minetto would be submerged and their water powers destroyed. The hydraulic canal on the east side of the river in Oswego would be intersected by the canal and its water supply cut off. The line would cross two high-

[1] The figures and quantities here given are for the final adopted line with lock No. 4 at Minetto.

[2] Lock No. 4 at Minetto.

[3] The discussion of the comparative cost of the two lines was written by Mr. Himes before the location of lock No. 4 was changed to Minetto and before the lock estimates were completed. The cost of the locks and dams on the river line is estimated at $4,500,000. The cost of the locks on the adopted line is $5,660,913, leaving a difference of $1,160,913 in favor of the river line in the cost of structures. This will offset the above difference in cost of excavation in favor of the adopted line, so that the costs of the construction of the channels themselves will be about the same on both lines. The river line, however, destroys many very valuable water rights, and the right of way would be much more expensive than for the adopted line.

way bridges and one railway bridge in the city, and the necessary draws would be a source of danger and delay to the shipping, as well as to the street and railroad traffic. The same number of bridges would be needed on the other line, but the traffic upon them would be much lighter, and they would be less troublesome.

But most important of all is the reduction in lift on the locks. The maximum lift on the adopted line is 21.4 feet, while on the river line it is 30.6 feet. The locks at Fulton would have lifts of 22.5 feet, and since the water used for lockage is regulated by that lock below the source of supply which consumes the most water, the saving of water on the adopted line would be equal to the difference between the volumes required by 22.5-foot and 30.6-foot locks, respectively. This saving would be considerable, and would materially lessen any possible chance of a shortage in the supply.

With the above advantages offered by the line west of the city, it was considered unnecessary to go any further with the estimates on the river line.

*Fulton to Peter Scott's swamp.*—It was supposed at first that the line beyond Fulton would follow the river to Phoenix, and then strike eastward into Peter Scott's swamp instead of leaving the river at Fulton and running across country to the swamp, as previously described. The survey showed the adopted line to be 1.8 miles shorter than the line through Phoenix and it is estimated to require about 2,700,000 cubic yards less excavation.

The estimate of the Phoenix line was made with less detail than the other, it being considered unnecessary to make a very close comparison of the two lines. For that reason, the rock excavation on the Phoenix line was not separated from the earth. The rock excavation in the river at Fulton alone, however, is greater than all the rock excavation on the adopted line, and there is much more rock between Fulton and Phoenix.

Such portions of the Phoenix line as lie in the river were estimated for a prism base of 400 feet as already described for the alternative line at Oswego.

In addition to the above differences in distance and excavation, the line through Phoenix would submerge the upper Fulton dam and the Phoenix dam, and the injury to the manufacturing plants which use their powers would add a large item to the cost. A new dam would be needed at Fulton, and the lock at that place would require a lift of about 30 feet. The disadvantage of such a high lift has already been stated and it is sufficient here to explain the necessity of such a lift.

The crest of the Phoenix dam has an elevation of about 361. The country above the dam is very low and flat, there being very little fall from Syracuse or Baldwinsville down to Phoenix. The area of land that would be affected by raising the canal water surface higher than the dam is so great, and about Syracuse the property bordering Onon-

daga Lake is so valuable, that the crest of the dam was taken as a limit above which the water must not be raised. It was necessary, therefore, to raise the water surface below Fulton from 331 to 361, the crest of the Phoenix dam. The cheapest way to do it is by a single lock; the way which would best economize the water is by two locks. In either case, by the high-level plan, a lock would be needed at Phoenix to rise from 361 to 376, so that if the two locks were used at Fulton there would be needed on the Phoenix line three locks to rise 45 feet, while on the adopted line the elevation is overcome by two locks.

These differences between the lines were deemed sufficient ground for discarding further estimates on the Phoenix line. It should be stated, however, that the river from Phoenix to Oswego was fully developed by the survey, and the maps will permit as complete a study of these alternative lines as of the line selected.

*Peter Scott's Swamp.*—In locating a line through Peter Scott's Swamp it was considered that, should a more thorough examination of it be made with a view to construction, and any reason be found why it would be inadvisable to build a dike and flood the swamp as already described, it would be well to know that the general plan for a canal would not be impaired. For that reason an alternative line has been located around the north side of the swamp on higher and firmer ground. No borings were made on this line, but it is so close to the adopted line that the information obtained is sufficient to make it very probable that no rock excavation would be necessary.

The following estimate shows the comparative cost of the two lines:

TABLE NO. 8.—*Comparative cost of lines passing Peter Scott's Swamp 30-foot channel.*

LINE THROUGH SWAMP.

| | |
|---|---|
| Earth excavation: | |
| Prism, 8,020,000 cubic yards, at 18 cents | $1,443,600 |
| Dike, 383,000 cubic yards, at 18 cents | 68,940 |
| Embankment, dike, 588,000 cubic yards, at 25 cents | 147,000 |
| Riprap, 71,000 cubic yards, at 90 cents | 63,900 |
| Total | 1,723,440 |

LINE NORTH OF SWAMP.

| | |
|---|---|
| Earth excavation, 10,440,000 cubic yards, at 18 cents | $1,879,200 |
| Cost of line through swamp | 1,723,440 |
| Difference of cost in favor of line through swamp | 155,760 |

*Sand Ridge Crossing.*—The line through Sand Ridge is believed to be as cheap as any that can be found. It was located in the field for the purpose of making borings, and having been thoroughly developed, all estimates have been based upon it.

If the canal should be built north of Peter Scott's Swamp, on the alternative line just described, the alignment could be improved by

crossing the ridge a little farther north. A profile of the northern crossing indicates a slightly greater amount of excavation, but no borings were made upon it and so the amount of rock which might be encountered can not be estimated.

*Sodus route.*—There is said to be an excellent natural harbor at Little Sodus, 25 miles west of Oswego, and an attempt was made to find a route for the canal which would make that port the northern terminus. The country on the west side of the Oswego River, between Phoenix and Fulton, is quite high, and the only possible opening is through Lake Neatahwanta, near Fulton. But the reconnoissance mentioned elsewhere showed the route to be so long and tortuous as to be wholly impracticable, and no survey was made of it.

*Change in locks.*—A rearrangement of locks on the proposed line north of Minetto is possible, by which the total lift from Lake Ontario to the river level, of 85.6 feet, could be made in three equal lifts, instead of four as proposed. The lift of each lock would then be 28.5 feet, instead of 21.4 feet, as before, and the principal results of the change would be an increased consumption of water and a saving of time in navigation equal, approximately, to that required to pass through one lock. The difference in cost would probably not be great, though no comparative estimate has been made, because it has been considered throughout that the plan which would require the least water to operate the canal would be preferable, at least until the adequacy of the water supply shall be finally demonstrated.

A similar change can be made near Fulton, in the low-level plan, to be described later. In this case three locks, two of them having equal lifts of 18 feet, and the third a lift varying between 12 feet and 19 feet, according to the stage of the Oneida reservoir, can be replaced by two locks, the lower one to have a lift of, say, 26 feet and the upper one a lift to vary between 22 feet and 29 feet. The effect of this change would be precisely similar to the first, and its feasibility depends almost wholly upon the water supply.

### CHANGES IN RAILROADS AND HIGHWAYS.

At Oswego, where the canal crosses the Delaware, Lackawanna and Western Railroad and the Rome, Watertown and Ogdensburg Railroad, a slight change of alignment would permit both roads to use one double-track drawbridge. The Rome, Watertown and Ogdensburg freight yard would require some alteration and the side track running down to the lake front should be moved to the east side of the canal.

The track of the Delaware, Lackawanna and Western Railroad would need to be raised a few feet for a short distance at Minetto.[1]

The New York, Ontario and Western Railway would require a single-track drawbridge at the canal crossing in the northern part of

[1] This will not be necessary with the change of location of lock No. 4.

Fulton and a change of alignment between the bridge and the station. Instead of providing another drawbridge for the same road near Ingalls, the estimate covers the relocation and construction of the road from Ingalls to the Oswego River, on the east side of the canal. The Fulton travel would be obliged to cross the highway bridge in the eastern part of the village and the freight traffic could enter the village over the bridge in the northern part of the village.

The Rome, Watertown and Ogdensburg Railroad would require a single-track drawbridge where it crosses the canal at Brewerton.

At Sylvan Beach the New York, Ontario and Western and Lehigh Valley railroads now use in common a single-track bridge over Wood Creek, and one single-track drawspan over the canal is all that would be needed at that place for both roads.

Each road has several miles of track that would need to be either raised and the embankments protected with riprap or else rebuilt on higher ground. The estimate for the high-level plan provides for raising the track; for the low-level plan the water surface in the Oneida reservoir would be so much higher that it is cheaper to change the location and rebuild the roads, so the estimate is based on such a change. According to the latter plan, an additional 4 miles of New York, Ontario and Western Railway track, on the north side of Oneida Lake, would need to be raised.

At Rome the estimate provides for a single-track drawbridge, to be used by the New York, Ontario and Western and Rome, Watertown and Ogdensburg railroads, and for building a four-track road entirely south of the canal, to be used by the New York Central and Hudson River Railroad. At present the immense passenger and freight traffic of that railroad passes through Rome and crosses the streets at grade. Many trains make no stop there, but go through the city at a high rate of speed, which is a constant menace to the public safety and a great expense to the company. If all trains were run over the line proposed the dangerous grade crossings would be abolished, a very sharp curve near the station would be eliminated, and through trains would not be obliged to slow up in passing the city. Rome passengers could cross the canal on the Rome, Watertown and Ogdensburg and New York, Ontario and Western trains, and the arrangement would be a great improvement for both the public and the railroads. The plan would, of course, meet with opposition, but it is probably the most expensive one that would be proposed; so whether it should ever be constructed or not, it will serve the purpose of making the present estimate large enough to cover any other plans that may be devised.

The advantage to the canal which justifies the plan requiring the largest first cost is the avoidance of two four-track drawbridges which would otherwise be necessary, and the operation of which would be no less vexatious and expensive to the railroad than to the canal.

The next railroad crossing is that of the Black River branch of the New York Central and Hudson River Railroad, near Utica. It would require a single-track drawbridge. The next and last crossing is that of the New York Central and Hudson River main line, 4.7 miles east of Utica. This crossing is unavoidable and requires a four-track drawspan.[1] The angle between the canal line and the railroad is very acute, and it will be necessary to rebuild the line far enough on each side of the canal to permit the angle of crossing to approximate 90 degrees.

The above crossings would be approximately the same for 21-foot or 30-foot channels on either the high-level or low-level plan.

Between Utica and Frankfort, according to the high-level plan, the water surface would have an elevation of 396, and several miles of the West Shore Railroad would need to be raised a few feet. With the low-level plan the high-water surface would be about 10 feet lower and no change would be needed.

Of the highways affected by the canal, drawbridges have been estimated for those near cities and villages which have considerable travel. There are two in Oswego and one each at Minetto, Fulton, Rome, Utica, Frankfort, Ilion, and Herkimer. The single-track railroad bridges at Fulton, Brewerton, and Sylvan Beach may also be used for highway purposes, since the railroad traffic upon them is not heavy. Table No. 2 gives the location, kind, and cost of all bridges on the high-level plan for both the 30 and 21 foot channels.

In all other cases where crossings are necessary steam ferries have been estimated for.

In cases where two or more highways intersect the canal within a comparatively short distance the estimates provide for the construction of new roads sufficient to bring them together at a single bridge or ferry.

### RIGHT OF WAY.

Besides the ground required by the canal itself a considerable area must be provided for spoil banks, and in the Mohawk Valley those banks should be as far as practicable from the canal, so as not to cause its slopes to cave into the water. About Oneida Lake a large area of land would be submerged, and it also is included in the estimate. The submerged area is much greater for the low-level plan than it is for the high-level plan.

The only water powers affected by either plan are those at the lower Fulton dam and at the Battle Island dam on the Oswego River. These two dams would be completely submerged, and their values for power purposes have been included in the estimate.

### LOW-LEVEL PLAN.

The conversion of Oneida Lake into a storage reservoir and the excavation of a channel through the Rome divide, deep enough to

[1] Estimated as two double-track drawspans.

extend the canal from the lake into the Mohawk Valley without locks would create a summit level 72.084 miles in length.

The level would begin a short distance east of Fulton, and its eastern terminus would be at Frankfort. The surface elevation of the reservoir when full would be 386; when empty it would be 379, thus making a storage depth of 7 feet.

The summit level at Rome under the former plan has a surface elevation of 416, which is 30 feet higher than the reservoir surface when full, and this plan will therefore effect a saving in lockage of 60 feet or more, according to the stage of the reservoir.

It will be observed that, according to the low-level plan, the surface of Oneida Lake is higher than under the high-level plan. No confusion will result from this fact if it is remembered that the terms are used only with reference to the summit levels.

The raising of Oneida Lake will increase the area of its water surface from 77.3 square miles at its present normal stage of 371 to 148.7 square miles when the reservoir is full. The area to be flooded includes the whole of Sylvan Beach, small portions of Cleveland, Constantia, and Brewerton, about 12 square miles of swamp, and a considerable area of farming land. Several miles of railroad about the eastern end of the lake would also be submerged and would need to be relocated on higher ground.

The survey about the lake extended generally only as high as the 380 contour, and beyond that the estimates are based upon the maps of the United States Geological Survey.

The weir at the crossing of the Oneida River west of Brewerton would be located as before, but its crest would be 10 feet higher, and a bulkhead with sluice gates would be needed to permit the discharge of water when needed for power purposes in the Oswego River.[1]

The embankment at the east end of the weir would be required to retain water about 16 feet in depth.

In passing Peter Scott's swamp the line selected runs around the swamp on the north instead of through it as before, because the water being 10 feet higher the increased cost of the embankment necessary to raise the level of the swamp and the difficulty of maintaining so high an embankment would remove whatever advantage the line through the swamp may possess for the other plan.

There is also a slight change of alignment in Wood Creek Valley. It is necessary, as has been explained before, that the high-level line should leave the creek and rise on higher and firmer ground so as to go over the divide. For the low-level line it is better to remain in the bottom of the valley, both because the volume of excavation would be less and because the material to be handled is not so hard and could be excavated at a smaller cost per cubic yard. This change is, however, so slight that the curvature and distance are nearly the same.

[1] This weir was estimated according to the plan adopted by the Board and explained in a footnote describing the same for the high-level plan.

The two locks at Fulton will have lifts of 18 feet instead of 22.5 feet as before, and a third lock, with a lift ranging from 12 feet to 19 feet, according to the stage of the reservoir, is located near the crossing of the New York, Ontario and Western Railway, 2.5 miles southeast from Fulton. Since the lift of this lock will generally be less than that of the locks below, and, therefore, require less water for lockage, provision is made to pass water around it to the lower locks by means of a bulkhead with sluice gates and a by-pass.

The two locks between Oneida Lake and Rome and the lock at Oriskany are not required in this plan. The next lock, and the last one in this division, is located at Frankfort. Its lift is 10 feet when the reservoir is full and 3 feet when it is empty. The water surface below the lock will have an elevation of 376, as before.

The Frankfort dam in this case has a fall of 10 feet, instead of 20 feet, as under the high-level plan, and it has a bulkhead with gates to pass water on to the locks below whenever that may be necessary.

The streams tributary to the line of the canal in the Mohawk Valley are received into the canal as before, save that on account of the greater depth of the channel the intake works are more extensive and their cost is increased.

It is a part of the low-level plan to store the water of Salmon River and allow it to flow down Fish Creek into Oneida Lake, thereby increasing the available water supply. An estimate for the necessary reservoir on Salmon River has been made in Appendix No. 16 and is added to the estimate for this plan.

The volume of water which it is expected to receive from Salmon River is such that it may be carried down Fish Creek without any considerable improvement to its channel. The gauging of the stream at McConnellsville, made by the water supply division in the spring of 1898, showed a flood discharge of 4,100 cubic feet per second, while the amount which is expected to pass through it from Salmon River is only 350 cubic feet per second, and will be controlled by gates, so that in case of floods it may be shut off entirely.

It is necessary to excavate a channel through the ridge separating Salmon River from Fish Creek. This channel is 3.5 miles long and has a slope of 0.00015. It is 10 feet deep, has a bottom width of 15 feet and side slopes of 1 on 2. Its cross section and slope are such that it will carry about twice the proposed discharge, but it may be desirable at times to increase that amount, and, moreover, the flow may be lessened at certain seasons by the growth of vegetation, so that a smaller channel would be found less satisfactory.

In addition to the estimate of the reservoir there is a dam across the Salmon River at the entrance to the proposed feeder, and several smaller dams across creeks which intersect the feeder, for which estimates have been made, and they are included herein, being indicated in the tabulated estimate by a footnote.

Table No. 9 gives the lengths of levels and lifts and costs of the

locks; Table No. 10 gives the location, kind and cost of the bridges for both 30 and 21 foot channels; Table No. 11 shows the alignment; Table No. 12 gives the different classes of navigation, with the percentages of each; and Tables Nos. 13 and 14 give the total estimated costs of 21-foot and 30-foot channels, respectively, all being based on the low-level plan.

TABLE No. 9.

| Number of lock. | Location of lock. | Single or double lock. | Elevation of low water. | | Lift in feet. | Length of level in miles. |
|---|---|---|---|---|---|---|
| | | | Below. | Above. | | |
| 1 | Oswego, N. Y | Single | 245.4 | 266.8 | 21.4 | |
| 2 and 3 | do | Double | 266.8 | 309.6 | 42.8 | .890 |
| 4 | Minetto, N. Y | Single | 309.6 | 331.0 | 21.4 | 4.384 |
| 5 | Fulton, N. Y | do | 331.0 | 349.0 | 18.0 | 5.900 |
| 6 | do | do | 349.0 | 367.0 | 18.0 | 1.193 |
| 7 | do | do | 367.0 | 379.0 | [1] 12.0- 19.0 | 1.648 |
| 8 | Frankfort, N. Y | do | 376.0 | 379.0 | [1] 3.0- 10.0 | 72.084 |
| | Headgates lock 10 to end of division | | | | | 4.529 |
| | Total | | | | 136.6-150.6 | 90.628 |

[1] Reservoir full.

COST.

| Number of lock. | 30-foot channel. | 21-foot channel. | Operating machinery, 30 foot and 21 foot channels. |
|---|---|---|---|
| 1 | $1,054,942 | $641,108 | $100,000 |
| 2 and 3 | 3,456,980 | 2,179,291 | 175,000 |
| 4 | 1,109,991 | 681,426 | 100,000 |
| 5 | 1,001,241 | 609,689 | 100,000 |
| 6 | 1,004,381 | 607,149 | 100,000 |
| 7 | 1,034,907 | 624,589 | 100,000 |
| 8 | 913,106 | 552,712 | 100,000 |
| Total | 9,575,538 | 5,895,964 | 775,000 |
| Operating machinery | 775,000 | 775,000 | |
| Total | 10,350,538 | 6,670,964 | |

TABLE No. 10.—*Bridges for low-level plan.*

| Location. | Station. | Kind of bridge. | Number of tracks. | Fixed or swing. | 30-foot channel. | | | 21-foot channel. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Number of spans. | Total length. | Estimated cost. | Total length. | Estimated cost. |
| Oswego, N. Y | 15 | Highway | 2 | Swing | 1 | 545.0 | $98,240 | 525.0 | $90,796 |
| Do | 87 | Railway | 2 | do | 1 | 550.0 | 221,429 | 530.0 | 196,161 |
| Near Oswego | 110 | Highway | | do | 1 | 545.0 | 116,534 | 525.0 | 98,138 |
| Minetto | 275 | do | | do | 1 | 235.0 | 19,986 | 195.0 | 16,650 |
| Fulton | 554 | Railway | 1 | do | 1 | 537.5 | 152,916 | 517.5 | 132,174 |
| Do | 582 | Highway | | do | 1 | 235.0 | 19,986 | 195.0 | 16,650 |
| Brewerton | 1403 | Railway | 1 | do | 1 | 537.5 | 156,434 | 517.5 | 149,118 |
| Near Sylvan Beach | 2740 | do | 1 | do | 1 | 537.5 | 150,538 | 517.5 | 139,202 |
| Rome | 3292 | Highway | | do | 1 | 545.0 | 93,764 | 525.0 | 92,320 |
| Do | 3304 | Railway | 1 | do | 1 | 537.5 | 125,218 | 517.5 | 117,054 |
| Utica | 3895 | do | 1 | do | 1 | 537.5 | 152,800 | 517.5 | 130,810 |
| Do | 4038 | Highway | | do | 1 | 545.0 | 106,950 | 525.0 | 91,356 |
| Near Utica | 4236 | Railway | 2 | do | 1 | 550.0 | 238,139 | 530.0 | 209,113 |
| Do | 4242 | do | 2 | do | 1 | 550.0 | 238,139 | 530.0 | 209,113 |
| Frankfort | 4555 | Highway | | do | 1 | 235.0 | 19,986 | 195.0 | 16,650 |
| Ilion | 4648 | do | | do | 1 | 545.0 | 103,354 | 525.0 | 84,086 |
| Herkimer | 4747 | do | | do | 1 | 545.0 | 103,354 | 525.0 | 84,086 |
| Total | | | | | | | 2,093,767 | | 1,849,567 |

TABLE NO. 11.—*Low-level plan.*

| Length of tangent. | Length of curve. | Minimum radius of curvature. | Degrees of curvature. | Percentage of tangent. | Percentage of curvature. |
|---|---|---|---|---|---|
| *Miles.* 70.762 | *Miles.* 19.866 | *Feet.* 4,523.4 | ° ′ 705 40 | 78.08 | 21.92 |

TABLE NO. 12.—*Low-level plan.*

| | Miles. | Per cent. |
|---|---|---|
| Open water | 20.928 | 23.09 |
| Improved waterways | 4.962 | 5.48 |
| Canal prism | 64.738 | 71.43 |
| Total | 90.628 | 100.00 |

TABLE NO. 13.—*Oswego-Mohawk Route, Western Division.*

LOW LEVEL PLAN—30-FOOT CHANNEL.

| | |
|---|---|
| Lake Ontario section (station −26+00 to −9+20): | |
| Excavation— | |
| Submerged rock, 349,670 cubic yards, at $2 | $699,340 |
| Breakwater, Appendix No. 3 | 1,190,317 |
| Crib work— | |
| Pine, 2,415,600 feet B. M., at $30 per M | 72,468 |
| Hemlock, 5,840,620 feet B. M., at $23 per M | 134,334 |
| Oak, 97,920 feet B. M., at $50 per M | 4,896 |
| Iron, 742,870 pounds, at 3 cents | 22,286 |
| Stone fill, 102,034 cubic yards, at 60 cents | 61,220 |
| Total | 2,184,861 |
| Oswego-Minetto section (station −9+20 to 288+00): | |
| Excavation— | |
| Earth, dry, 11,866,321 cubic yards, at 20 cents | 2,373,264 |
| Rock, dry, 1,969,596 cubic yards, at 65 cents | 1,280,237 |
| Retaining wall, 143,479 cubic yards, at $4 | 573,916 |
| Masonry in by-passes, 4,300 cubic yards, at $4 | 17,200 |
| Slope wall, 68,448 square yards, at $1.10 | 75,293 |
| Back fill, 449,336 cubic yards, at 25 cents | 112,334 |
| Crib work— | |
| Pine, 2,374,400 feet B. M., at $30 per M | 71,232 |
| Hemlock, 6,992,000 feet B. M., at $23 per M | 160,816 |
| Oak, 96,920 feet B. M., at $25 per M | 2,423 |
| Iron, 786,632 pounds, at 3 cents | 23,599 |
| Stone fill, 125,856 cubic yards, at 60 cents | 75,514 |
| Railroad and highway changes | 29,660 |
| Locks— | |
| No. 1 | 1,054,942 |
| Nos. 2 and 3 | 3,456,980 |
| No. 4 | 1,109,991 |
| Lock-operating machinery— | |
| 2 sets, single, at $100,000 | 200,000 |
| 1 set, double | 175,000 |

| | |
|---|---|
| Oswego-Minetto section, etc.—Continued. | |
| Bridges | $426,189 |
| Right of way— | |
| City property, 277 acres, at $2,080 | 576,160 |
| Farm land, 729 acres, at $200 | 145,800 |
| Total | 11,940,550 |
| Minetto-Fulton section (station 288+00 to 550+00): | |
| Excavation— | |
| Earth, 1,911,170 cubic yards, at 18 cents | 344,011 |
| Rock, dry, 117,268 cubic yards, at 65 cents | 76,224 |
| Slope walls, 14,508 square yards, at $1.10 | 15,959 |
| Minetto dam (No. 1)— | |
| Excavation, 25,567 cubic yards, at 20 cents | 5,113 |
| Masonry in dam and abutments, 44,913 cubic yards, at $6 | 269,478 |
| Cofferdams, estimated cost | 55,000 |
| Highway and railroad changes | 25,670 |
| Right of way— | |
| Farm land, 1,154 acres, at $100 | 115,400 |
| Swamp land, 408 acres, at $12.50 | 5,100 |
| Water rights, Battle Island Dam | 150,000 |
| Total | 1,061,955 |
| Fulton-Brewerton section (station 550+00 to 1410+00): | |
| Excavation— | |
| Earth, 29,876,982 cubic yards, at 18 cents | 5,377,857 |
| Rock, 2,033,872 cubic yards, at 65 cents | 1,322,017 |
| Masonry— | |
| Retaining wall, 198,210 cubic yards, at $4 | 792,840 |
| By-pass, 600 cubic yards, at $4 | 2,400 |
| Slope wall, 513,405 square yards, at $1.10 | 564,746 |
| Back fill, 723,338 cubic yards, at 25 cents | 180,834 |
| Crib work— | |
| Pine, 2,381,600 feet B. M., at $30 per M | 71,448 |
| Hemlock, 9,173,000 feet B. M., at $23 per M | 210,979 |
| Oak, 77,000 feet B. M., at $50 per M | 3,850 |
| Iron, 979,024 pounds, at 3 cents | 29,371 |
| Stone fill, 154,800 cubic yards, at 60 cents | 92,880 |
| Oneida River dam— | |
| Excavation, 51,000 cubic yards, at 18 cents | 9,180 |
| Embankment, 27,000 cubic yards, at 15 cents | 4,050 |
| Masonry in dam and abutments, 21,270 cubic yards, at $6 | 127,620 |
| Stoney gates | 46,250 |
| Railroad and highway changes | 73,400 |
| Steam ferries, 4, at $20,000 | 80,000 |
| Locks— | |
| No. 5 | 1,001,231 |
| No. 6 | 1,004,381 |
| No. 7 | 1,034,907 |
| Lock-operating machinery, 3 sets single, at $100,000 | 300,000 |
| Bridges | 329,336 |

| | |
|---|---|
| Fulton-Brewerton section, etc.—Continued. | |
| Right of way— | |
| Village property, Fulton, N. Y., 55 acres, at $2,600 | $143,000 |
| Farm land, 5,910 acres, at $100 | 591,000 |
| Swamp land, 2,446 acres, at $12.50 | 30,575 |
| Water rights | 806,000 |
| Total | 14,230,152 |
| Brewerton-Canada Creek section (station 1410+00 to 2970+00): | |
| Excavation— | |
| Earth, 21,464,652 cubic yards, at 8 cents | 1,717,172 |
| Rock, wet, 505,500 cubic yards, at $2 | 1,011,000 |
| Slope wall, 259,251 square yards, at $1.10 | 285,187 |
| Railroad and highway changes | 264,675 |
| Bridges | 156,538 |
| Right of way— | |
| Farm land, 36,714.65 acres, at $100 | 3,671,465 |
| Swamp land, 4,800 acres, at $12.50 | 60,000 |
| Salmon River feeder— | |
| Earth excavation, 1,207,300 cubic yards, at 15 cents | 181,095 |
| Reservoir[1] | 1,350,000 |
| Dam No. 53[1] | 366,500 |
| Dam No. 55[1] | 5,100 |
| Dam No. 56[1] | 1,000 |
| Dam No. 57[1] | 57,000 |
| Dam No. 58[1] | 87,600 |
| Guard gate, No. 7[1] | 14,000 |
| Total | 9,228,332 |
| Canada Creek-Fort Bull (station 2970+00 to 3165+00): | |
| Excavation— | |
| Earth, 12,387,183 cubic yards, at 20 cents | 2,477,437 |
| Rock, dry, 2,789,719 cubic yards, at 70 cents | 1,952,803 |
| Masonry— | |
| Retaining wall, 219,402 cubic yards, at $4 | 877,608 |
| Receivers, 5,500 cubic yards, at $4 | 22,000 |
| Slope wall, 28,713 square yards, at $1.10 | 31,584 |
| Back fill, 512,027 cubic yards, at 25 cents | 128,007 |
| Highway changes | 600 |
| Steam ferry, 1 | 20,000 |
| Right of way— | |
| Farm land, 943 acres, at $100 | 94,300 |
| Total | 5,604,339 |
| Fort Bull-Herkimer section (station 3165+00 to 4789+91.5): | |
| Excavation— | |
| Station 3165 to 3280— | |
| Earth, 12,861,717 cubic yards, at 22 cents | 2,829,578 |
| Rock, 102,500 cubic yards, at 70 cents | 71,750 |
| Station 3280 to 3420— | |
| Earth, 9,245,002 cubic yards, at 18 cents | 1,664,100 |
| Rock, 3,902,848 cubic yards, at 70 cents | 2,731,994 |

[1] From estimate for water supply, high level, Appendix No. 16.

| | |
|---|---|
| Fort Bull-Herkimer section, etc.—Continued. | |
| Excavation—Continued. | |
| Station 3420 to 3590— | |
| Earth, 16,644,368 cubic yards, at 22 cents | $3,661,761 |
| Rock, 133,235 cubic yards, at 70 cents | 93,265 |
| Station 3590 to 3780— | |
| Earth, 9,021,975 cubic yards, at 18 cents | 1,623,956 |
| Rock, 4,465,075 cubic yards, at 70 cents | 3,125,553 |
| Station 3780 to 3980— | |
| Earth, 15,008,168 cubic yards, at 18 cents | 2,701,470 |
| Rock, 121,002 cubic yards, at 70 cents | 84,701 |
| Station 3980 to 4180— | |
| Earth, 12,390,681 cubic yards, at 22 cents | 2,725,950 |
| Station 4180 to 4533— | |
| Earth, 18,295,204 cubic yards, at 22 cents | 4,024,945 |
| Station 4533 to 4789+91.5— | |
| Earth, 11,123,827 cubic yards, at 18 cents | 2,002,289 |
| Rock, 117,023 cubic yards, at 70 cents | 81,916 |
| Excavation for receivers not in above, 520,300 cubic yards, at 18 cents | 93,654 |
| Excavation for drainage channels— | |
| Earth, 6,568,000 cubic yards, at 15 cents | 985,200 |
| Retaining wall, 341,268 cubic yards, at $4 | 1,365,072 |
| Masonry for receivers and by-passes, 41,100 cubic yards, at $4 | 164,400 |
| Slope wall, 991,540 square yards, at $1.10 | 1,090,694 |
| Back fill, 862,371 cubic yards, at 25 cents | 215,593 |
| Crib work— | |
| Pine, 1,431,600 feet B. M., at $30 per M | 42,948 |
| Hemlock, 4,553,340 feet B. M., at $23 per M | 104,734 |
| Oak, 75,840 feet B. M., at $50 per M | 3,792 |
| Iron, 523,344 pounds, at 3 cents | 15,700 |
| Stone fill, 79,126 cubic yards, at 60 cents | 47,476 |
| Frankfort dam— | |
| Excavation, 90,000 cubic yards, at 18 cents | 16,200 |
| Masonry in dam and abutments, 2,650 cubic yards, at $6 | 15,900 |
| Gates | 6,000 |
| Railroad and highway changes | 412,320 |
| Steam ferry, 1 | 20,000 |
| Lock, No. 8 | 913,106 |
| Lock-operating machinery— | |
| 1 set, single | 100,000 |
| Bridges | 1,181,704 |
| Right of way— | |
| 10,335 acres, at $100 | 1,033,500 |
| Total | 35,251,221 |

TOTAL COST.

| | |
|---|---|
| Lake Ontario section | $2,184,861 |
| Oswego-Minetto section | 11,940,550 |
| Minetto-Fulton section | 1,061,955 |
| Fulton-Brewerton section | 14,230,152 |
| Brewerton-Canada Creek section | 9,228,332 |
| Canada Creek-Fort Bull section | 5,604,339 |
| Fort Bull-Herkimer section | 35,251,221 |
| Total | 79,501,410 |

TABLE No. 14.—*Oswego-Mohawk route, western division.*

LOW-LEVEL PLAN, 21-FOOT CHANNEL.

| | |
|---|---|
| Lake Ontario section (station −20+00 to −9+20): | |
| Excavation— | |
| Submerged rock, 152,361 cubic yards, at $2 | $304,722 |
| Breakwater, Appendix No. 3 | 721,380 |
| Crib work— | |
| Pine, 2,416,000 feet B. M., at $30 per M | 72,480 |
| Hemlock, 3,096,800 feet B. M., at $23 per M | 71,226 |
| Oak, 83,600 feet B. M., at $50 per M | 4,180 |
| Iron, 490,585 pounds, at 3 cents | 14,718 |
| Stone fill, 63,325 cubic yards, at 60 cents | 37,995 |
| Total | 1,226,701 |
| Oswego-Minetto section (station −9+20 to 288+00): | |
| Excavation— | |
| Earth, dry, 9,300,777 cubic yards, at 20 cents | 1,860,155 |
| Rock, dry, 843,884 cubic yards, at 65 cents | 548,525 |
| Retaining wall, 97,906 cubic yards, at $4 | 391,624 |
| Masonry in by-passes, 4,300 cubic yards, at $4 | 17,200 |
| Slope wall, 88,288 square yards, at $1.10 | 97,117 |
| Back fill, 348,900 cubic yards, at 25 cents | 87,225 |
| Crib work— | |
| Pine, 2,374,400 feet B. M., at $30 per M | 71,232 |
| Hemlock, 4,894,400 feet B. M., at $23 per M | 112,571 |
| Oak, 53,760 feet B. M., at $50 per M | 2,688 |
| Iron, 593,600 pounds, at 3 cents | 17,808 |
| Stone fill, 94,576 cubic yards, at 60 cents | 56,746 |
| Railroad and highway changes | 29,660 |
| Locks— | |
| No. 1 | 641,108 |
| Nos. 2 and 3 | 2,179,291 |
| No. 4 | 681,426 |
| Lock-operating machinery— | |
| 2 sets single, at $100,000 | 200,000 |
| 1 set double | 175,000 |
| Bridges | 377,745 |
| Right of way— | |
| City property, 277 acres, at $2,080 | 576,160 |
| Farm land, 729 acres, at $200 | 145,800 |
| Total | 8,269,081 |
| Minetto-Fulton section (station 288+00 to 550+00): | |
| Excavation— | |
| Earth, 914,740 cubic yards, at 18 cents | 164,653 |
| Slope wall, 13,414 square yards, at $1.10 | 14,755 |
| Minetto dam— | |
| Excavation, 25,567 cubic yards, at 20 cents | 5,113 |
| Masonry in dam and abutments, 44,913 cubic yards, at $6 | 269,478 |
| Cofferdams | 55,000 |
| Railroad and highway changes | 25,670 |

| | |
|---|---|
| Minetto-Fulton section, etc.—Continued. | |
| Right of way— | |
| Water rights, Battle Island dam | $150,000 |
| Farm land, 1,154 acres, at $100 | 115,400 |
| Swamp land, 408 acres, at $12.50 | 5,100 |
| Total | 805,169 |
| Fulton-Brewerton section (station 550+00 to 1410+00): | |
| Excavation— | |
| Earth, 22,243,558 cubic yards, at 18 cents | 4,003,840 |
| Rock, 905,227 cubic yards, at 65 cents | 588,398 |
| Masonry— | |
| Retaining wall, 128,268 cubic yards, at $4 | 513,072 |
| By-pass, 600 cubic yards, at $4 | 2,400 |
| Slope wall, 530,906 square yards, at $1.10 | 583,997 |
| Back fill, 465,160 cubic yards, at 25 cents | 116,290 |
| Crib work— | |
| Pine, 2,222,000 feet B. M., at $30 per M | 66,660 |
| Hemlock, 3,794,260 feet B. M., at $23 per M | 87,268 |
| Oak, 85,800 feet B. M., at $50 per M | 4,290 |
| Iron, 918,168 pounds, at 3 cents | 27,545 |
| Stone fill, 230,243 cubic yards, at 60 cents | 138,146 |
| Oneida River dam— | |
| Excavation, 51,000 cubic yards, at 18 cents | 9,180 |
| Embankment, 27,000 cubic yards, at 15 cents | 4,050 |
| Masonry in dam and abutments, 21,270 cubic yards, at $6 | 127,620 |
| Stoney gates | 46,250 |
| Railroad and highway changes | 73,400 |
| Steam ferries, 4, at $20,000 | 80,000 |
| Locks— | |
| No. 5 | 609,689 |
| No. 6 | 607,149 |
| No. 7 | 624,589 |
| Lock operating machinery— | |
| Three sets, single, at $100,000 | 300,000 |
| Bridges | 297,942 |
| Right of way— | |
| Village property, Fulton, N. Y., 55 acres, at $2,600 | 143,000 |
| Farm property, 5,910 acres, at $100 | 591,000 |
| Swamp land, 2,446 acres, at $12.50 | 30,575 |
| Water rights, Fulton, N. Y | 806,000 |
| Total | 10,482,350 |
| Brewerton-Canada Creek section (station 1410+00 to 2970+00): | |
| Excavation— | |
| Earth, 14,079,204 cubic yards, at 8 cents | 1,126,336 |
| Rock, wet, 30,646 cubic yards, at $2 | 61,292 |
| Slope wall, 259,261 square yards, at $1.10 | 285,187 |
| Railroad and highway changes | 264,675 |
| Bridges | 139,292 |
| Right of way— | |
| Farm land, 36,714.65 acres, at $100 | 3,671,465 |
| Swamp land, 4,800 acres, at $12.50 | 60,000 |

| | |
|---|---|
| Salmon River feeder: | |
| Earth excavation, 1,207,300 cubic yards, at 15 cents | $181,095 |
| Reservoir [1] | 1,350,000 |
| Dam No. 53 [1] | 366,500 |
| Dam No. 55 [1] | 5,100 |
| Dam No. 56 [1] | 1,000 |
| Dam No. 57 [1] | 57,000 |
| Dam No. 58 [1] | 87,600 |
| Guard gate No. 7 [1] | 14,000 |
| Total | 7,670,542 |
| Canada Creek-Fort Bull section (station 2970+00 to 3165+00): | |
| Excavation— | |
| Earth, 11,773,284 cubic yards, at 20 cents | 2,354,657 |
| Rock, 1,364,600 cubic yards, at 70 cents | 955,220 |
| Masonry— | |
| Retaining wall, 96,670 cubic yards, at $4 | 386,680 |
| By-pass, 5,500 cubic yards, at $4 | 22,000 |
| Slope wall, 73,683 square yards, at $1.10 | 81,051 |
| Back fill, 193,550 cubic yards, at 25 cents | 48,388 |
| Highway changes | 600 |
| Steam ferry, 1 | 20,000 |
| Right of way— | |
| Farm land, 943 acres, at $100 | 94,300 |
| Total | 3,962,896 |
| Fort Bull-Herkimer section (station 3165+00 to 4789+91.5): | |
| Excavation— | |
| Station 3165 to 3280— | |
| Earth, 11,421,882 cubic yards, at 22 cents | 2,512,814 |
| Rock, 41,015 cubic yards, at 70 cents | 28,710 |
| Station 3280 to 3420— | |
| Earth, 9,005,048 cubic yards, at 18 cents | 1,620,909 |
| Rock, 2,587,541 cubic yards, at 70 cents | 1,811,279 |
| Station 3420 to 3590— | |
| Earth, 14,530,927 cubic yards, at 22 cents | 3,196,804 |
| Station 3590 to 3780— | |
| Earth, 8,528,606 cubic yards, at 18 cents | 1,535,149 |
| Rock, 2,773,258 cubic yards, at 70 cents | 1,941,281 |
| Station 3780 to 3980— | |
| Earth, 12,649,373 cubic yards, at 18 cents | 2,276,887 |
| Rock, 121,002 cubic yards, at 70 cents | 84,701 |
| Station 3980 to 4180— | |
| Earth, 10,285,965 cubic yards, at 22 cents | 2,262,912 |
| Station 4180 to 4533— | |
| Earth, 14,605,749 cubic yards, at 22 cents | 3,213,265 |
| Station 4533 to 4789+91.5— | |
| Earth, 8,600,133 cubic yards, at 18 cents | 1,548,024 |
| Rock, 25,190 cubic yards, at 70 cents | 17,633 |
| Excavation for receivers not in above— | |
| Earth, 524,046 cubic yards, at 18 cents | 94,328 |

[1] From estimate for water supply, high level, Appendix No. 16.

| | |
|---|---|
| Fort Bull-Herkimer section, etc.—Continued. | |
| Excavation for draining channels— | |
| Earth, 6,568,000 cubic yards, at 15 cents | $985,200 |
| Retaining wall, 200,096 cubic yards, at $4 | 800,384 |
| Masonry for receivers, etc., 41,100 cubic yards, at $4 | 164,400 |
| Slope wall, 1,020,253 square yards, at $1.10 | 1,122,278 |
| Back fill, 484,170 cubic yards, at 25 cents | 121,043 |
| Crib work— | |
| Pine, 1,770,000 feet B. M., at $30 per M | 53,100 |
| Hemlock, 6,328,300 feet B. M., at $23 per M | 145,551 |
| Oak, 88,920 feet B. M., at $50 per M | 4,446 |
| Iron, 714,144 pounds, at 3 cents | 21,424 |
| Stone fill, 101,872 cubic yards, at 60 cents | 61,123 |
| Frankfort dam— | |
| Excavation, 90,000 cubic yards, at 18 cents | 16,200 |
| Masonry in dam and abutments, 2,650 cubic yards, at $6 | 15,900 |
| Gates | 6,000 |
| Railroad and highway changes | 412,320 |
| Steam ferry, 1 | 20,000 |
| Lock No. 8 | 552,712 |
| Lock-operating machinery— | |
| 1 set single | 100,000 |
| Bridges | 1,034,588 |
| Right of way— | |
| Farm land, 10,335 acres, at $100 | 1,033,500 |
| Total | 28,814,865 |

TOTAL COST.

| | |
|---|---|
| Lake Ontario section | $1,226,701 |
| Oswego-Minetto section | 8,269,081 |
| Minetto-Fulton section | 805,169 |
| Fulton-Brewerton section | 10,482,350 |
| Brewerton-Canada Creek section | 7,670,542 |
| Canada Creek-Fort Bull section | 3,962,896 |
| Fort Bull-Herkimer section | 28,814,865 |
| Total | 61,231,604 |

WATER SUPPLY—LOW-LEVEL PLAN.

For the purpose of this discussion the period from April to November, inclusive, is called the navigation period, and that from December to May, inclusive, the storage period. It will be observed that the first two months of the navigation period are the last two months of the storage period.

The amount of water required for the summit level may be divided into two parts—that lost by evaporation and that consumed by lockage. To determine the amount of water which may be lost by evaporation, reference is made to the measurements of evaporation at the Rochester waterworks, given in Table No. 15, and to the record of precipitation during the navigation period for those portions of the Oneida and Mohawk watersheds which will drain into the proposed summit level, given in Table No. 16.

TABLE No. 15.—*Showing evaporation during navigation periods at Rochester, N. Y., 1892 to 1896, inclusive.*[1]

| | Inches. |
|---|---|
| 1892 | 30.86 |
| 1893 | 30.02 |
| 1894 | 29.27 |
| 1895 | 34.38 |
| 1896 | 32.23 |

TABLE No. 16.—*Record of precipitation during navigation periods on portions of Oneida and Mohawk watersheds tributary to proposed summit level, 1826–1898, inclusive.*[2]

[Depths given in inches.]

| | 1826. | 1827. | 1828. | 1829. | 1830. | 1831. | 1832. | 1833. | 1834. | 1835. |
|---|---|---|---|---|---|---|---|---|---|---|
| Pompey | ..... | 27.75 | 28.94 | 23.90 | 26.75 | ..... | 22.40 | 28.59 | ..... | 24.26 |
| Utica | 20.81 | 36.70 | 30.88 | 24.97 | 34.28 | 26.33 | 34.21 | 28.94 | 26.85 | 30.42 |
| Cazenovia | ..... | ..... | ..... | ..... | 31.00 | 29.75 | 27.94 | 30.24 | 25.89 | 26.61 |
| Whitesboro | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 17.72 | 18.24 |
| Average | 20.81 | 32.23 | 29.91 | 24.44 | 30.68 | 28.04 | 28.18 | 29.26 | 23.49 | 24.88 |

| | 1836. | 1837. | 1838. | 1839. | 1840. | 1841. | 1842. | 1843. | 1844. | 1845. |
|---|---|---|---|---|---|---|---|---|---|---|
| Pompey | 14.63 | 25.71 | 20.97 | 20.72 | 25.60 | 19.16 | 23.53 | 24.52 | ..... | ..... |
| Utica | 19.37 | ..... | ..... | 24.92 | 29.44 | 29.94 | 41.34 | 33.95 | 23.02 | 28.65 |
| Cazenovia | ..... | 30.35 | 35.54 | 25.43 | 33.46 | 21.23 | 32.16 | 34.20 | 29.62 | 26.90 |
| Whitesboro | 22.26 | 17.53 | 21.01 | 20.26 | 41.20 | ..... | ..... | ..... | ..... | ..... |
| Average | 18.75 | 24.53 | 25.84 | 22.83 | 32.43 | 23.44 | 32.34 | 30.89 | 26.32 | 27.78 |

| | 1846. | 1847. | 1848. | 1849. | 1850. | 1851. | 1852. | 1853. | 1854. | 1855. |
|---|---|---|---|---|---|---|---|---|---|---|
| Pompey | ..... | ..... | ..... | ..... | 40.59 | 28.38 | 31.59 | 31.39 | 23.13 | 23.63 |
| Utica | 28.08 | ..... | ..... | ..... | ..... | ..... | 29.44 | 28.73 | ..... | ..... |
| Cazenovia | 29.71 | 25.22 | 28.53 | 29.51 | ..... | ..... | ..... | ..... | ..... | ..... |
| Clinton | ..... | ..... | ..... | ..... | ..... | 30.07 | 33.20 | 31.83 | 30.38 | 38.07 |
| Palermo | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 24.30 | 24.80 |
| Average | 28 90 | 25.22 | 28.53 | 29.51 | 40.59 | 29.23 | 31.41 | 30.65 | 25.94 | 28.83 |

| | 1856. | 1857. | 1858. | 1859. | 1860. | 1861. | 1862. | 1863. | 1864. | 1865. |
|---|---|---|---|---|---|---|---|---|---|---|
| Utica | ..... | ..... | ..... | ..... | ..... | 32.75 | 28.69 | 28.57 | ..... | ..... |
| Clinton | 23.00 | 48.90 | 32.29 | 35.64 | 37.05 | ..... | 21.19 | 25.21 | 27.12 | ..... |
| Palermo | 25.90 | 30.30 | 28.10 | 33.90 | 31.40 | 32.20 | 32.06 | 33.40 | 33.80 | 32.05 |
| South Trenton | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 33.51 | ..... |
| Oneida | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 48.26 |
| Average | 24.45 | 39.60 | 30.20 | 34.77 | 34.23 | 32.48 | 27.29 | 29.06 | 31.48 | 40.16 |

| | 1866. | 1867. | 1868. | 1869. | 1870. | 1871. | 1872. | 1873. | 1874. | 1875. | 1876. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Palermo | 31.81 | 19.90 | 22.05 | 25.60 | 15.25 | 17.70 | 23.60 | 23.73 | 28.40 | 20.40 | 22.70 |
| South Trenton | 38.47 | 36.54 | 39.78 | 48.73 | 35.20 | 34.60 | 31.67 | 32.64 | 29.56 | 38.87 | 33.67 |
| Oneida | 48.92 | 51.26 | 57.25 | 56.03 | 46.83 | 41.47 | ..... | ..... | 52.60 | ..... | 35.33 |
| Average | 39.73 | 35.90 | 39.69 | 43.45 | 32.43 | 31.26 | 27.64 | 28.19 | 36.85 | 29.64 | 30.57 |

[1] From Report New York State Engineer and Surveyor, 1896.

[2] From data furnished by the water-supply division.

TABLE NO. 16.—*Record of precipitation during navigation periods on portions of Oneida and Mohawk watersheds, etc.*—Continued.

| | 1877. | 1878. | 1879. | 1880. | 1881. | 1882. | 1883. | 1884. | 1885. | 1886. | 1887. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Utica | | | | | 25.67 | 26.02 | 28.32 | 23.37 | 38.07 | 34.75 | 23.07 |
| Palermo | 21.35 | 28.60 | 18.10 | 23.37 | 15.71 | 13.79 | 22.90 | 13.78 | 22.65 | 20.63 | 17.33 |
| Oneida | 34.65 | | | | | | | | | | |
| Average | 28.00 | 28.60 | 18.10 | 23.37 | 20.69 | 19.91 | 25.61 | 18.58 | 30.36 | 27.69 | 20.20 |

| | 1888. | 1889. | 1890. | 1891. | 1892. | 1893. | 1894. | 1895. | 1896. | 1897. | 1898. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Utica | 30.96 | 33.27 | 44.85 | 21.17 | 39.97 | | | | | | |
| Palermo | 22.20 | 25.29 | 30.67 | 18.13 | 34.95 | 25.00 | 26.74 | 18.81 | 20.41 | 23.03 | 24.05 |
| Rome | | | 48.36 | | 34.11 | 30.07 | 30.29 | 22.89 | 25.10 | 28.91 | 38.47 |
| Phœnix | | | | | | 30.59 | 27.82 | 18.68 | 22.53 | 28.00 | 30.23 |
| Average | 26.58 | 29.28 | 41.29 | 19.65 | 36.34 | 28.55 | 28.28 | 20.13 | 22.68 | 26.65 | 30.92 |

The maximum evaporation recorded during the navigation periods for the years 1892 to 1896, inclusive, occurred in 1895, and amounted to 34.38 inches. This was an excessively dry year throughout the lake region, and the evaporation is not likely to be exceeded.

The year of least precipitation during the navigation period, shown in Table No. 16, is 1879, and the amount for that year is 18.1 inches. Subtracting this minimum precipitation from the maximum evaporation gives 16.28 inches for the maximum depth of water that will be taken from the surface of the reservoir during any navigation season by evaporation.

The area of the surface of the reservoir when full is 148.7 square miles. This area reduced to square feet and multiplied by the depth of evaporation in feet gives 5,624,086,000 cubic feet, the volume of water required for evaporation.

It is assumed, by the direction of your Board, that a flow of 1,500 cubic feet per second throughout the navigation period will afford an abundant supply for lockage, and that of this amount 350 cubic feet per second can be supplied from the Salmon River reservoir. A flow of 1,150 cubic feet per second remains to be provided. This flow continued throughout the navigation period, two hundred and forty-four days, amounts to 24,243,840,000 cubic feet, and when added to the volume required for evaporation makes a total of 29,867,926,000 cubic feet which must be obtained from the area naturally tributary to the summit level.

It is desirable that a quantity of water sufficient for canal purposes shall be supplied, in addition to that now in use for water powers. In the event of the construction of the canal, it would be necessary, in order to accomplish this purpose, hat the amount of water now used for power be carefully measured and provision made for the continual flow of that amount both at Little Falls and in the Oswego River. If we except the three summer months, there is generally a

large volume of water wasted over the dams on both the Oswego and Mohawk rivers, and it is here assumed that the Seneca River alone will furnish water for power purposes on the Oswego during the storage period, and that West Canada Creek alone will furnish water for powers at Little Falls during that period. The portion of the Oswego watershed not made tributary to the summit level has an area of about 3,654 square miles, and the portion of the Mohawk watershed above Little Falls not made tributary to the summit level, and which includes West Canada Creek, has an area of 646 square miles.

The natural flow from the area that would drain into the summit level for the months not included in the storage period is not considered a part of the supply available for canal purposes and may be used for water powers as at present.

While it is impossible without further data to say that by this arrangement the various water powers will continue to receive this present supply of water, it seems reasonable to expect that they will, and such is assumed to be the case in this discussion.

The portion of the Oneida watershed to be made tributary to the summit level has an area of 1,348 square miles, the portion of the Mohawk watershed to be made tributary to the summit level has an area of 660 square miles, and the sum of these areas, 2,008 square miles, is the total from which the volume 29,867,926,000 cubic feet must be obtained during the storage period.

It is assumed that during the above period 60 per cent of the precipitation will find its way into the reservoir. This assumption was made after a study of Table No. 17, in which the precipitation and run-off statistics of several streams whose records were available have been arranged to show the percentage of precipitation which appears in the discharge of the streams during the storage period of years of average and minimum precipitation.

TABLE No. 17.—*Rainfall and run-off data for storage period.*

| Stream. | Period of observation. | Area of watershed in square miles. | For mean precipitation during observation period. | | | For year of minimum precipitation. | | | Percentage of precipitation. |
|---|---|---|---|---|---|---|---|---|---|
| | | | Precipitation in inches. | Run-off in inches. | Percentage of precipitation. | Year. | Precipitation in inches. | Run-off in inches. | |
| Muskingum | 1888–1895 | 5,828.0 | 18.82 | 9.57 | 50.85 | 1895 | 13.04 | 4.04 | 30.98 |
| Upper Genesee | 1894–1896 | 1,070.0 | 19.58 | 10.20 | 52.09 | 1895 | 13.20 | 5.63 | 42.65 |
| Upper Hudson | 1891–1896 | 4,500.0 | [1]20.80 | 15.95 | 76.68 | 1895 | [2]15.79 | 11.68 | 73.97 |
| Croton | 1870–1896 | 338.0 | 23.44 | 18.00 | 76.79 | 1872 | 14.57 | 11.59 | [2]79.55 |
| Passaic | 1888–1893 | 822.0 | 25.49 | 21.03 | 82.50 | 1892 | 22.26 | 14.44 | 64.87 |
| Sudbury | 1875–1895 | 75.0 | 23.28 | 17.58 | 75.52 | 1883 | 16.78 | 9.70 | 57.81 |
| Mystic | 1878–1895 | 26.9 | 22.41 | 15.08 | 67.29 | 1883 | 16.24 | 7.41 | 45.63 |
| Cochituate | 1863–1895 | 18.9 | 23.08 | 14.89 | 64.51 | 1872 | 14.51 | 8.88 | 61.20 |

NOTE.—This table was computed from data collected by G. W. Rafter and published in the Reports of the New York State Engineer for 1895 and 1896 and in Water Supply and Irrigation Papers of the United States Geological Survey, No. 24.

[1] Precipitation on "northern plateau."

[2] A percentage of run-off greater than the average in a year of minimum precipitation seems very improbable and is probably due to an error.

The year of minimum precipitation on the Upper Hudson is 1895. In that year the percentage of precipitation which appeared in the run-off at Mechanicville is 73.97. The conditions affecting precipitation and run-off which prevail upon the watersheds of the Oneida and Upper Mohawk rivers probably resemble those of the Hudson more closely than the conditions which prevail upon any of the other streams. Geographically the summit level is nearer to the Hudson than to any other stream of which the records are available, and the climatic conditions of the two localities are similar. The streams draining into the summit level have channels which are generally stony and precipitous, though perhaps they are not so torrential in character as the tributaries of the Hudson. The Hudson River record of run-off has been kept under favorable conditions and should be quite reliable, and it includes the year 1895, which is noted for its general dryness.

On the other hand, the precipitation record used in computing the percentage of run-off for the Hudson is the record of the "northern plateau," an area which includes observation stations north and west of the Upper Hudson basin and only one or two stations within that basin. Much of the Hudson basin lies in the heart of the Adirondacks, where no observations of precipitation have been made, and the record of the "northern plateau" has been used as affording the nearest approximation to the precipitation of the Hudson. It may therefore be surmised that since in 1895, the year of minimum precipitation, the percentage of run-off of the Hudson was so great, it being 73.97, the actual precipitation on the Hudson was probably greater than that of the "northern plateau." If such is the case, the effect would be to reduce the percentage of run-off, and this probability was considered in deciding upon the percentage to be used in calculating the run-off from the Oneida-Mohawk watershed.

If 60 per cent of the precipitation during the storage period is to afford a volume of 29,867,926,000 cubic feet of water, then the total volume of precipitation, or 100 per cent, must be 49,779,877,000 cubic feet, which is equal to a depth of 10.67 inches over 2,008 square miles.

This depth exceeds the recorded precipitation during the storage period in but two years out of the seventy-three years' record (this record is given in full in Appendix No. 16. The observation stations considered are the same as those in Table No. 16), once in 1829, when the precipitation was 9.34 inches, and once in 1837, when it was 8.95 inches. The average precipitation during the storage periods for the seventy-three years was 19 inches, or 78 per cent more than the amount required.

The record of precipitation is not wholly satisfactory. In several years we have the record for but a single station. The record at Oneida of a mean annual precipitation of 64.83 inches is abnormally large, and the difference between the records of Utica and Whitesboro sug-

gests a difference in methods of measurement. The latter places are on the south side of the Mohawk Valley, not over 3 miles apart, and the mean annual precipitation for five years—1834, 1835, 1836, 1839, and 1840—at Utica is 36.98 inches, while for the same years at Whitesboro it is 31.83 inches. Such a discrepancy is unaccountable.

In this discussion evaporation from water surfaces during the months December to March, inclusive, has been neglected, and also the fact that the area of the proposed reservoir is about 7 per cent of the watershed, and upon its surface the precipitation will fall directly. These factors will, in a measure, balance each other, the net result being too small for consideration in a problem involving the use of such rough data. For the same reason no account has been made of the present Erie Canal reservoirs and feeders, which, though small, will nevertheless assist a little to increase the water supply.

We have next to inquire concerning the capacity of the reservoir.

Since April and May are, by reason of the large run-off of water during those months, made a part of the storage period, it would seem unnecessary for the storage supply to be greater than is needed for the months of June to November, inclusive. The consumption of water for the months of April and May will be, in a year of maximum evaporation, as per Rochester data:

| | Cubic feet. |
|---|---|
| Lockage | 6,060,960,000 |
| Evaporation, 8.44 inches on 148.7 square miles | 2,915,681,000 |
| Total | 8,976,641,000 |

This volume is equivalent to a run off of 1.86 inches on 2.008 square miles, or a precipitation of 1.92 divided by 0.6 = 3.2 inches.

TABLE NO. 18.—*Precipitation on Oneida and Upper Mohawk watersheds during the months of April and May for the twelve years of the record, showing the least precipitation for those months:*

| | Inches. | | Inches. |
|---|---|---|---|
| 1879 | 2.05 | 1872 | 3.62 |
| 1891 | 3.02 | 1896 | 3.65 |
| 1873 | 3.08 | 1877 | 3.80 |
| 1828 | 3.17 | 1887 | 3.88 |
| 1881 | 3.32 | 1884 | 4.11 |
| 1847 | 3.33 | 1837 | 4.14 |

Table No. 18 gives the recorded precipitation in April and May for the twelve years of the record showing the least precipitation during those months. The necessary quantity, 3.2 inches, was lacking in but four years—1879, 1891, 1873, and 1828. In those years the precipitations during the months of April and May were respectively 2.05 inches, 3.02 inches, 3.08 inches, and 3.17 inches. The only year in which the deficiency is at all serious is in 1829, and during the storage period of that year the precipitation was abundant. It may therefore be considered that, since the months of April and May constitute

about one-fourth of the navigation period, a storage volume equal to three-fourths of the total volume of water to be furnished by the Oneida and Mohawk watersheds will be all that is required. This total volume, the Salmon River supply not included, is 29,867,926,000 cubic feet, and three-fourths of it is 22,400,945,000 cubic feet.

The capacity of the reservoir between elevations 379 and 386 is 25,302,400,000 cubic feet, a surplus of 2,901,455,000 cubic feet above what is needed. In addition to this, the water surface could be raised 1 or 2 feet above elevation 386 without doing any harm, since the locks are to be built to elevation 391 and the embankment at the weir in Oneida River to elevation 396.

Because of the uncertainty of calculations based upon rainfall data it may be well to inquire what conditions would develop in the event of a year so dry that a sufficient supply of water failed to be collected during the storage period. It is seen at once that there is at the beginning of the storage period a surplus of water in the reservoir of 2,901,455,000 cubic feet, the amount by which its capacity exceeds the demand. This amount alone will furnish water for lockage and evaporation at the usual rate for nineteen days.

Referring to the Salmon River reservoir, there would probably be many years when the whole or a part of its waters would not be needed. In such a case during the succeeding storage period only a fraction of the drainage from the Salmon River basin would be needed to fill that reservoir and the remainder could be turned directly into Oneida Lake. If it were not needed in the lake, it would run over the weir in Oneida River and thence into Lake Ontario, but if it should happen that the Oneida reservoir was not filled by the drainage naturally tributary to it, then this overflow from Salmon River might help to fill it. It may be well to state that in calculating the volume of the Oneida storage reservoir no account was made of the ground water which would drain from the shores of the lake when the water surface is lowered. The area bordering the lake which it is proposed to submerge contains about 12 square miles of swamp land, the drainage from which, when the water surface is lowered, would be considerable.

The occurrence in succession of two years of maximum dryness is a rare contingency, but because of its possibility it may be profitable to ask what would happen if, after using the reserve supply above described, there came another year of equal dryness. In that case there would be a deficiency in the ordinary supply and the reserve described above would be wholly wanting. The case would be unfortunate, of course, but it would not cause the suspension of navigation. Suppose a 30-foot channel has been constructed, then, when the water supply begins to fail, the available depth in the summit level will diminish; but the volume of water lying between elevations 379 and 377 is 6,244,760,000 cubic feet and would furnish water for evaporation

and lockage at the usual rate for forty-one days. With the water surface at an elevation of 377 there would still be a depth in the channel of 28 feet, and it would only be necessary for the boats to carry smaller cargoes until the great drought had passed.

The foregoing discussion has not been carried to that degree of refinement that would be desirable with more exact data. The precipitation records have not been kept at a sufficient number of stations, and those we have exhibit some vagaries which raise suspicion as to their value. The percentage of run-off used in the computations may prove too high and the provision for the noninterference with water powers may not prove satisfactory. But the conditions discussed include a maximum length of navigation season, a maximum lockage, maximum evaporation, and a minimum rainfall. The average conditions would be more favorable, and in the extreme case Oneida Lake would continue to act as a reservoir no matter how great the demand upon it. If drawn down 8 feet below proposed low water, it would still have an area of about 80 square miles, and a month's traffic would lower it but little. So, if it be assumed that the average water supply is sufficient, navigation need never be suspended, though at times the maximum depth of water may not be available in the summit level.

This condition, is in striking contrast to that which would exist with a short high-summit level dependent upon a feeder supply. With such a plan, if the storage supply were exhausted or if the banks of the feeder or reservoir should fail, the water would at once be cut off from the canal and navigation wholly suspended.

In conclusion, it may be stated that notwithstanding the unsatisfactory character of the data used, the results indicate a strong probability that a sufficient water supply may be obtained by this plan, and it would be well to verify them by a series of discharge measurements on the Oneida and Mohawk rivers. Such measurements, in connection with gauge records covering years of maximum and minimum discharge, would permit a proper and final design for the water supply.

A gauge was established at Brewerton in January, 1898, and was read under the direction of the undersigned until June 1, 1899, and the record preserved. Mr. F. H. Newell, hydrographer in charge, United States Geological Survey, has since continued the readings, and each year will add to the value of the record.

The effect of floods on Oneida Lake has been discussed under the high-level plan with an area of water surface of about 96 square miles. Since by the low-level plan the area would be 148.7 square miles, or about 55 per cent greater, the fluctuation due to freshets would be much less, and so small as to be of no especial interest.

The advantages shown by the low-level plan may now be summed up as follows:

If at any time the supply of stored water should prove insufficient, navigation need not be suspended, since the Oneida reservoir could be drawn below the low-water elevation, and thus furnish a continuous supply of water at the expense of a slightly decreased depth of water in the summit level.

The difficulties and uncertainties of maintaining a feeder about 90 miles long and extending for a considerable portion of its length across the drainage lines of the country would be avoided.

There would be a saving of two locks with their attendant delays to navigation, and if the three locks at Fulton should be combined in two, three locks would be avoided. In either case, the reduction in total lift would vary between 60 feet and 74 feet, according to the stage of the reservoir.

The loss of water by leakage, though very small in either case, would be somewhat less, since between Oneida Lake and Frankfort the water surface would be lower than the ground surface, whereas with the high level there would be a few places where the water might seep through the canal banks into Wood Creek or the Mohawk River.

## DESCRIPTION OF SURVEYS.

The survey was made to cover the route described in the 1896 Report of the United States Deep Waterways Commission, and also such minor variations as were deemed worthy of investigation. Besides the usual base line, stadia work, and test boring described in Appendix No. 9, the survey included triangulation of Oswego Harbor and Oneida Lake and soundings in Lake Ontario, Oswego River, Oneida River, Oneida Lake, Wood Creek, and Mohawk River.

The survey was begun at Oswego, N. Y., in October, 1897. The force consisted at first of a base-line party, in charge of Mr. E. E. Hart, and two stadia parties, in charge of Messrs. C. E. Curtis and F. A. Bagg, respectively. A sounding party and a level party began work early in November, and one boring machine was started in Peter Scott's swamp in the latter part of December. Mr. J. C. Hoyt was in charge of the soundings, Mr. E. Hilborn, jr., was selected to run the levels, and Mr. A. W. Saunders was employed to superintend the borings.

An effort was made in the beginning to keep the force together as closely as possible for the purpose of getting started right.

The survey from the Oswego light-house to the first lock in the Oswego Canal was controlled by triangulation which was made by the base-line party. Upon its completion, the measurement of the base line along the river was begun.

The stadia work was begun at the lake shore with a party on each side of the Oswego River.

When the base-line party got well ahead of the stadia work, it was used, together with the level party, to locate sounding ranges. These

parties carried along the base line and levels, and located the soundings until December 27, when the running ice caused a suspension of sounding, and the base line was then pushed forward to Oneida Lake as rapidly as possible.

The work upon Oneida Lake could be done best in the winter time, when its surface was frozen, and plans were therefore made to do it all, if possible, during the first winter. That would necessarily cause a break in the continuity of the survey, but the importance of completing the lake work during the ice season made it the controlling feature of the survey. As it was impossible to foretell either the duration of the ice or the amount of work which might be necessary in order to find the best channel through the lake, it was deemed advisable to concentrate the whole force on the lake and push the work as rapidly as possible. For this purpose the stadia work on the Oswego River was suspended and the parties moved to Brewerton about the middle of January.

The sounding and triangulation were both begun January 17. Mr. Curtis's party had been assigned to the triangulation, Mr. Bagg's party to the soundings, and the force was considerably increased by the addition of a number of laborers.

Up to that date very little time had been lost because of bad weather, and there was so much topography to be taken about Oneida Lake that a new stadia party was organized and set at work on the north shore of the lake January 17.

The borings in Peter Scott's swamp were completed about the middle of January, and as soon as the sounding party was out of the way two boring machines were started on the lake.

In order to find the deepest channel a line of soundings was made across the lake at Constantia, and another at North Bay. A transit line was then run from the outlet of the lake at Brewerton to the deepest part of the lake opposite Constantia, and from there to the deepest point in the lake opposite North Bay. This line was used as a base from which to lay out the soundings. A parallel line 300 feet south was also staked and soundings made along both lines at intervals of 100 feet. At intervals of 500 feet lines were staked perpendicular to the base and sounded far enough on either side to show that the deepest water lay within the sounded area.

A sounding reel and an ice auger, such as are described in Appendix E E E of the Report of the Chief of Engineers, United States Army, for 1895, were used in the work. The reel was found very convenient and rapid, but the auger proved no more economical than axes.

The sounding was completed February 7 and the laborers discharged. The stadia party resumed its work at Brewerton.

The base-line party, after crossing the lake, extended its line up the Wood Creek Valley to the high ground near New London. The valley is subject to frequent floods in the spring, which rise above the

banks of the creek, and it was intended to run the line far enough to permit its continuance at any time that might be desired.

The party next returned to the lake and measured a base near North Bay and one near Brewerton for use in the triangulation. The base line being then far in advance of the rest of the survey the party was assigned to stadia work in Sand Ridge, where the thick woods and brush made it desirable to do the work before the leaves came out in the spring.

While the base-line party was crossing the lake the level line had been carried around the lake on the north, and, when the base line was suspended, the level party was broken up temporarily and its members divided among the other parties.

The material in the bed of the lake proved to be mostly thin mud, with occasional bars of sand and gravel, and a little rock near the outlet. The boring was therefore very easy and made rapid progress.

It was completed February 9, and the party moved back to Sand Ridge and worked in the small ponds and marshes in that vicinity while the ice lasted. In the spring the borings were completed between Phoenix and Brewerton and during the first week of June two boring machines were started at Sylvan Beach and one on the Oswego River at Phoenix. The latter was mounted on a small flatboat, which had an open well near the center through which the drill and casing could be worked.

The triangulation of Oneida Lake was completed March 15 and the party resumed its stadia work on the Oswego River. A description of the triangulation is given under a separate heading.

As soon as the lake work was completed the efforts of the corps were directed toward the completion of the work between Brewerton and Oswego. The soundings of the river were completed in a short time, and in the latter part of May the stadia work was completed and the two original parties moved to the south shore of Oneida Lake, while the base-line and level parties resumed their work near New London. There was no further interruption of the base-line work until its completion at Herkimer, July 11.

On May 24 a reconnoissance was made by your Board of a route from Fulton westward toward Sodus. The route was found to be so crooked and the work so heavy that no survey was made of it. On the same day a proposed line from Fulton southeasterly through Ingalls Crossing into Peter Scott's Swamp was examined. A preliminary stadia line had already been run over the ground, and it appeared so favorable that its complete development was ordered. When the base line had been completed to Herkimer the parties engaged upon it were therefore moved back to Fulton to run this line.

Soundings and borings were made for a harbor at Oswego in July, one stadia party and a sounding party being sent from Wood Creek and a boring machine from Phoenix for that purpose. The soundings

were made from a steam launch running on ranges, and the soundings located by two transits on the shore. The borings were made from a small flatboat, the same that began work on the river at Phoenix early in June.

On the completion of the harbor work the stadia and sounding parties returned to Wood Creek and the boring machine was moved back up the river. There was no further interruption of the sounding and stadia work and they were both completed to Herkimer early in November.

A second boring machine was started near Fulton August 9, and the two machines continued their work along the Oswego and over the line from Fulton to Peter Scott's Swamp until its completion in the middle of January, 1899.

The boring party east of Oneida Lake found very hard material near New London, and the progress was so slow that the force was gradually increased until there were six machines at work. The hard material was passed a short distance west of Rome and the progress down the Mohawk Valley was more rapid. The borings were completed during the first week in January, 1899.

The plotting of the survey was continued at Rome until March 1, 1899, when the force was moved to the office of the board at Detroit. Since the method pursued in the mapping varies in some respects from that pursued by the other corps it is described with some detail under a separate heading.

In the spring of 1899 a few additional borings were made at the site of a proposed lock near Fulton, and in July a complete development was made of a line from Minetto to Lake Ontario, running west of Oswego.

Table No. 19 indicates the size of the force and the progress of the work from its beginning in October, 1897, to the closing of the field office, February 28, 1899.

The men engaged upon the survey have taken great interest in the work and are worthy of credit for their earnest efforts to accomplish the best possible results. I am particularly indebted for the active sympathy and cooperation of the following men who had charge of instrument parties in the field: F. A. Bagg, A. E. Broenniman, C. E. Curtis, E. E. Hart, J. Hayes, E. Hilborn, jr., and W. A. Miller. A. W. Sanders was superintendent of borings. W. J. Bergen, A. Haring, and H. H. Ross assisted in the Detroit office and deserve mention.

TABLE No. 19.—*Approximate statement of monthly progress of field work.*

| Month. | Transit line, distance run in miles. | | Levels, distance run in miles. | | Topography. | | | Soundings. | | Borings. | | Number of names on pay roll. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Base line. | Auxiliary line. | Base line. | Auxiliary line. | Triangulations, number of angles observed. | Square miles surveyed. | Days lost on account of storms. | Miles of channel sounded.[1] | Area sounded in square miles.[2] | Number of holes. | Total depth in feet.[3] | Surveys. | Borings. |
| 1897. | | | | | | | | | | | | | |
| Oct | 6.01 | | 5.54 | 0.4 | 168 | | | .83 | | | | 32 | |
| Nov | 5.34 | 8.32 | 16.28 | 12.9 | | | 3.5 | 7.06 | | | | 28 | |
| Dec | 14.40 | 8.34 | 22.01 | 13.0 | | | 4.5 | 7.33 | | 3 | 81 | 31 | 12 |
| 1898. | | | | | | | | | | | | | |
| Jan | 30.24 | .63 | 69.58 | 4.6 | 6 | | 1.0 | | | 33 | 1,302 | 52 | 15 |
| Feb | 2.91 | | 7.03 | | 36 | | 4.4 | 2.98 | | 113 | 3,398 | 48 | 18 |
| Mar | | 5.21 | | 5.1 | 39 | | 1.4 | 7.79 | | 15 | 1.287 | 38 | 21 |
| Apr | | | | | | | 2.8 | | | 45 | 1,757 | 35 | 20 |
| May | 9.62 | | 15.18 | | | | 4.7 | | | 34 | 1.241 | 33 | 25 |
| June | 21.35 | | 47.97 | | | | 1.2 | 25.72 | | 70 | 3.828 | 41 | 23 |
| July | 17.02 | | 24.46 | .4 | | | .7 | 9.46 | | 46 | 1.435 | 44 | 28 |
| Aug | | | | | | | 3.2 | 22.98 | | 66 | 2.798 | 45 | 45 |
| Sept | | | | | | | 1.5 | 3.02 | | 54 | 2.166 | 47 | 55 |
| Oct | | | | | | | 3.6 | 3.60 | | 109 | 6.045 | 44 | 47 |
| Nov | | | | 1.2 | | | | | | 97 | 4.978 | 39 | 53 |
| Dec | | | | | | | | | | 55 | 2.931 | 32 | 48 |
| 1899. | | | | | | | | | | | | | |
| Jan | | | | | | | | | | 10 | 464 | [4]22 | 18 |
| Feb | | | | | | | | | | | | [4]22 | |
| Total | 106.89 | 22.5 | 208.05 | 37.6 | 249 | 132.30 | 32.5 | 88.77 | 15.80 | 750 | 33.711 | | |

[1] Includes all other soundings.
[2] Includes Lakes Ontario, Onedia, and Pleasant.
[3] Depth of water not included.
[4] Drafting.

NOTE.—The small amount of field work done in the spring and summer of 1899 is not included. The time lost by storms while taking topography is given as the best available data of that character. It is the average number of days lost by the several stadia parties at work.

## TRIANGULATION.

The Oswego Harbor was covered by a net of simple triangles. The work was done by the base-line party, Mr. E. E. Hart in charge.

The base was 461.24 feet long. The number of triangles was 47 and the longest side 1,435.3 feet. The area covered was $\frac{11}{100}$ square mile.

The triangles were all small and no especial care was necessary to insure satisfactory results. Five sides were both measured and computed, and the results are as follows:

| Side. | Measured length. | Computed length. | Discrepancy. |
|---|---|---|---|
| A B | 564.59 | 564.58 | +0.01 |
| B C | 915.52 | 915.68 | — .16 |
| $H_1$ I | 1,309.57 | 1,309.49 | + .08 |
| $R_1$ S | 150.77 | 150.76 | + .01 |
| *a g* | 491.43 | 491.43 | .00 |

The only difficulty encountered was in dodging lumber piles and buildings.

The triangulation controls the survey from the outer light-house to the first base-line station near Oswego Canal lock No. 18.

The triangulation of Oneida Lake was performed by Mr. C. E. Curtis and the members of his stadia party, aided, during the latter part of the work, by Mr. E. Hilborn, jr., and an additional rodman.

The work consisted of the preliminary reconnoissance, selection and marking of stations, measuring base lines, and observing the angles. The adjustment of the angles and the computations were performed later in the office at such times as were convenient.

Two Buff & Berger 6¼-inch transits were used on the work. The verniers of both instruments read to 30 inches. The one with which the work was begun had been in use about three months. It had an inverting telescope. When Mr. Hilborn was assigned to the work, the second transit was purchased new. It was just like the one already in use, save that it had an erecting telescope.

The object of the triangulation was to extend the base line of the survey across Oneida Lake and to establish points along its shores with which to control the topography. The greater part of the lake had been mapped by the United States Geological Survey, the map of which was very useful in locating the various stations.

The general scheme adopted was a chain of six quadrilaterals and a single triangle, the triangle being at the western end of the lake. The western vertex of the triangle was called A and the stations along the shores were lettered consecutively B, C, D, E, F, G, and H, the subscript $n$ and $s$ being used to indicate whether the station was on the north or south shore. The lines $B_n$ $B_s$ and $G_s$ and $H_s$ were selected as bases, and their lengths measured on the ice.

There were also three stations, $1_s$, $2_n$, $3_n$, located outside of the main system, and in connection with other stations they formed two additional triangles.

The stations were first marked on the geological map, care being taken that no angle should scale less than 30°. Flags were then set up around the lake at the various stations and observed with a field glass to see if the adjacent stations were intervisible, and the angles measured roughly with a pocket compass. Many of the stations had to be shifted several times before the desired conditions could be obtained. The map was not wholly accurate, and it was found that trees and buildings prohibited the use of some of the lines first planned.

The line $D_s$, $E_s$ had to be cleared for about 1,000 feet through a piece of thick woods.

It was found that two angles were slightly less than 30°, and since they could not be increased without great difficulty they were allowed to stand. Most of the stations were located at the edge of the water in order to avoid trees. Two stations, $F_n$ and $G_n$, were on quite high ground, but the view from each was obstructed by trees and buildings, and two wooden towers had to be erected.

When it was found that $F_n$ and $G_n$ could not be used without the towers, other plans were studied. The only alternate locations avail-

able were such that if adopted they would make several of the angles considerably less than 30°, and they could not be used at all without a further reconnoissance. It seemed to be a question whether it were better to incur a further expense and delay for reconnoissance and accept angles of a size which were too small for the best results or to build the towers. The cost of the two towers was $106.40, and the expense for a further reconnoissance and setting the signals would have been not less than $25, so it is possible that $81.40 was paid for the sake of having the angles greater instead of less than 30°.

The signals used were pine boards, 1 inch by 12 inches by 8 feet long. The edges of the boards were chamfered, so that they could not be seen when a signal was being observed. On the face of the board were painted a series of black 12-inch squares, with their diagonals in the axis of the board. The body of the signal was painted white, so that in pointing the telescope the vertical wire would bisect the series of angles made by the squares.

A tapered oaken plug was bolted to the foot of each signal. The axis of the taper plug was in line with the axis of the signal. The station was marked by a cedar post set in the ground, with its top just below the surface. A tapered hole was bored in the post to receive the signal. When the signal was thus set up, it was securely guyed to avoid motion or injury by the wind. When the signals were not in use, the holes in the posts were stopped by oak plugs made for the purpose, and well greased with tallow to keep out the water. No trouble was experienced at any time in removing the plugs and setting the signals.

These signals were used on sides that were 5 miles long, and were plainly seen on clear days, but there was much hazy weather and light snow, which made the seeing bad, so it was finally decided to work at night. Six tubular lanterns, with parabolic reflectors and 1-inch flat wicks, were procured and mounted on stakes which set in the station posts just as the signal boards did. The center of the flame was plumbed over the center of the hole. These signals worked very well, and could be plainly seen 6½ miles, which was the length of the longest line.

The towers were each 36 feet high, and were built of rough hemlock fastened together with nails. Each tower consisted of a tripod to support the instrument and a staging for the observer and recorder. The staging had four posts placed at the corners of a 12-foot square. With the legs of the tripod there were in all 7 posts. Each post was built up of 2 by 4s nailed together so as to break joints. The posts were braced with boards, 1 by 6 inches, nailed horizontally and diagonally in panels, excepting that the bottom horizontal braces of the tripod were 2 by 4s. The staging was wholly independent of the tripod, so that no jar occasioned by the wind or moving on the staging could affect the instrument.

A box was built up in the center of the tower to protect the plumb bob string from the wind. The box was supported entirely by the staging.

At one corner of the staging a ladder was built to give access to the platform at the top.

The legs of the tripod were set into the ground about 18 inches, and rested on large flat stones. A platform was built on the bottom of the tripod and weighted with several wagonloads of stone.

Angles were read successfully from the towers when the wind blew so hard that the transit box was blown to the ground, and the motion of the tower was never so great that the motion of the movable head of the transit was not sufficient to center the plumb bob.

The board on which the transit rested, when in the box, was fastened to the tripod with wood screws, and a hole cut in the center for the plumb bob.

The station posts were set in the ground after the towers were built so as to avoid any difficulty in centering the tower.

The different stations were all referenced before reading the angles, so that if disturbed they could be relocated and also that they might be readily found later by the stadia parties. An azimuth was also measured to some local object or stake, so that the stadia parties could readily check on it and not be obliged to depend on a sight to another triangulation station.

An azimuth observation was made at A and another at $H_n$, for which the azimuths of the triangulation lines were computed, making due allowance for convergence.

The bases $B_s$ $B_n$ and $G_s$ $H_s$ were measured by the base-line party. The conditions were favorable for good measurements. $B_s$ and $B_n$ were close to the lake at about the elevation of the water surface. $G_s$ was similarly located, but $H_s$ was about 20 feet from the shore and 3 feet higher. The weather was mild and cloudy. A path was shoveled, in each case, along the ice, and the tape rested in snow water; so its temperature was practically constant. The tape lengths were marked with a knife blade on the top of little pine pegs driven in the ice, holes being bored with an auger for that purpose. Each base was measured twice in opposite directions and a new set of pegs used each time. A tension of 12 pounds was applied each time to the tape, and the pegs were lined with a transit.

After correcting for tape error and temperature, the measured lengths of $G_sH_s$ differed by $\frac{114}{1000}$. The mean corrected length was 11,521.215, and the proportional error was 1 in 101,000. For $B_sB_n$ the measured lengths differed by $\frac{3}{100}$. The mean corrected length was 6,429.480, and the proportional error was 1 in 213,300.

At each corner of a quadrilateral there were measured the angle formed by its sides and the two angles formed by the sides and the diagonal. There were, therefore, 12 angles measured in each quadrilateral,

and since there were 6 quadrilaterals and 3 triangles, 2 of them small and of secondary importance, there were, in all, 81 angles. Each angle in the quadrilaterals was repeated twenty-four times, and if for any reason a set of readings was interrupted before it was complete an entire new set of twenty-four was made.

Two methods of pointing were used, the first being as follows: Let A be the signal to the left and B the signal to the right; then with the telescope direct point on A, clamp below, read, loosen above, point on B, clamp above, read, loosen below. Perform the same operation six times, save that the reading is not to be made again until after the sixth pointing on B. Then without disturbing the reading, reverse the telescope and make six pointings on A and B as before, save that no reading is to be made after pointing on A nor until after the sixth pointing on B.

Next loosen the plates and shift them so that the readings will come on a different part of the limb. Then make twelve pointings as before, save that when the upper plate is loose, the motion should be from B to A. The operation is now, point on B, clamp below, read, loosen above, point on A, clamp above, read, loosen below, point on B, and so on. Do not read again until after the sixth pointing on A and again after the twelfth pointing on A.

Both verniers were always used when making a reading.

In this method, while a set of twelve repetitions are being made, the motion of the upper plate on the lower is always in the same direction, and any slipping has a cumulative effect. It was found that this method gave angles a trifle too small; so the second method was adopted. It differs from the first only in that the second six repetitions are made from B to A instead of from A to B. Likewise the third and fourth sets of six are made in opposite directions. This method eliminated the errors due to slipping and produced better results. The first method was used in triangle A $B_n$ $B_s$ and the two quadrilaterals next east and gave values a little too small. The second method was used in the remaining quadrilaterals and gave half of the values too small and half of them too large, the mean being more nearly correct than in the former case.

The quadrilaterals and triangles all closed within 10 seconds, save $B_n$ $B_s$ $C_n$ $C_s$ in which the error of closure was 15.8 seconds. It was not considered worth while to try to reduce the error, as its effect would occasion no practical inconvenience or injury to the work.

When it became necessary to increase the force, the work was prosecuted by one party at night and by the other in the daytime. The night party occupied the stations having the longest sights and was able to see the signals without difficulty.

The delays due to wind, snow, and mist were about the same as in the daytime, the advantage being wholly in the fact that the night signals could be seen a greater distance.

$D_n$ was located on a small island which was so low that the ice covered it. There was some motion of the ice during the triangulation; so to be sure of the position of the station the angles in the triangle $D_n$ $2_n$ $3_n$ were measured thirteen times, while D was in use. Fortunately no motion occurred.

The quadrilaterals were adjusted according to the "Rigorous method," given on page 514 of Johnson's Theory and Practice of Surveying, thirteenth edition. The spherical excess, being less than 1 second, was not considered.

## MAPPING.

The survey has been mapped on mounted sheets, the size of which, inside the working limit, is 25 by 37 inches. East of Sand Ridge the survey has been plotted to a scale of 1 in 5,000. West of and including a portion of Sand Ridge the surface of the country is more irregular, and a larger scale was necessary to clearly show the country; so it was mostly plotted on a scale of 1 in 2,500.

The base line, stadia circuits, and triangulation have been plotted by latitudes and departures and the courses all scaled after plotting. The work was simplified and the chances for error lessened by making the sides of the sheets parallel to the meridians and the top of the maps toward the north. This plan also permitted a sheet to be laid out at any time on any part of the survey, because the latitude and departure of its working limits could generally be fixed independently of the other sheets.

Contours have been drawn having a vertical interval of 2 feet, save in some few cases where it seemed improbable that the country might be affected by any canal location. In those cases a 10-foot interval was used.

The conventions furnished by the Board have been followed throughout the work, but while they were used sufficiently to show clearly the topography of the country, care has been exercised to avoid everything in that line not wholly necessary, to the end that the maps might be a useful medium for an engineering study rather than an exhibition of artistic skill.

There has been some shrinkage of the paper, which amounted, on a few sheets, to one-tenth of an inch in each direction, but generally it has been much less. It has occurred generally after the plotting has been done, and scalings from the maps may be corrected so as to eliminate its effect. The method of laying out the sheets prevents any cumulative errors due to this cause.

The process of mapping is naturally separated into two principal divisions, pencil work and pen work. The former includes plotting the base line, triangulations, and stadia circuits, plotting the topography and sketching contours. The latter includes inking the figures, making the topographical conventions, drawing contours and right

lines, and lettering. In addition to these there is checking the work and cleaning the sheets.

In doing the work the men assigned to each of these subdivisions have been continued long enough on one class of work to acquire considerable skill, so that a good degree of progress could be made. For instance, in sketching contours a continued improvement in skill and rapidity was observed for two or three months after beginning.

Some parts of the mapping, such as sketching contours, lettering, and making the conventional signs, required especial skill and natural ability, and this arrangement permitted the execution of all such work by the men who were best fitted for it. It was sometimes necessary to shift the men from one part to another, in order to keep the work moving forward in an orderly manner, and in that way the monotony of the work was varied somewhat.

This method of mapping has several advantages which were well suited to the situation. In the first place, it permits the use of a number of engineers who are not skilled draftsmen, and many of the men who had been employed on the survey could be retained for work on the maps. Moreover, a sufficient number of skilled draftsmen to do the whole work was hard to find, and had they been found would have required larger salaries. By keeping a man on one piece of work for several weeks, as, for example, plotting the base line and stadia circuits, he becomes thoroughly familiar with it and is much less liable to make errors than where he only plots the lines on a single sheet at a time and then takes up another part of the work. There is a natural tendency among men to interpret notes according to their memory, and while it is true that some men have excellent memories, it was desired to secure a set of notes which were not dependent upon such assistance and to know that the plotting was done in strict conformity thereto.

With this method the work was so divided and distributed that no one had a chance to make any use of such familiarity with the topography as he may have gained in the field, and if the notes were not clear the fact was quickly discovered and steps taken to remedy the fault and guard against its recurrence. A memorandum book for each of the stadia parties was kept in the office, and in it were recorded all questions or doubts which arose concerning the notes taken by that party. During the progress of the survey, when all the notes in one field book had been plotted, these memoranda, together with the field book, were returned to the party in the field which had taken the notes, and the proper corrections and additions made. By this means the stadia parties were continually posted regarding their weak points and the quality of their work improved. The plan was so successful that during the latter half of the survey it became very unusual to find in the notes any important defects.

This method also secured a degree of uniformity in keeping the notes and making computations that could have been attained in no other way. The work, in fact, was reduced to a system and was, therefore, at all times under complete control.

The principal errors guarded against in the mapping were such as might occur in plotting the stadia readings and in sketching the contours. In order to eliminate these, after the contours had been sketched the maps were carefully examined by men who gave nearly their whole time to that work, and all irregular or unusual features, such as crooked property lines or peculiar contours, were investigated and sometimes replotted. All boring notes were plotted twice, as their importance was much greater than that of single contour points and it was imperative that they should be correct. The maps were checked immediately after the contours were sketched in pencil, and then throughout the process of inking a close watch was kept for errors and omissions.

Another part of the office work consisted of figuring the latitudes and departures and adjusting the circuits, checking the reduction of stadia readings, and extending the elevations of contour points.

Much of the computing that had been done in the field was refigured in the office. It was found that checking which had been done in the field by the parties who took the notes was less reliable than that done in the office. This was probably because the members of the field parties were unable to do as good work in the evening after an active day in the field as were the office men who did no other work, and also because they were so familiar with the notes that any error was more readily passed over and repeated than where the checking was done by men who were using the notes for the first time. It has therefore been a general rule on the survey that all checking of numerical work, as well as drafting, should be done by parties who had nothing to do with the original work.

In the beginning of the survey the field work was checked by having each party plot its own work roughly on protractor sheets. At that time there were only two stadia parties at work. They were located very near together, and the checking was fairly well done. It was found, however, that to do the work thoroughly would require the addition of a draftsman and a computer to each party. Even with this change it would have been difficult to keep the checking close up to date, because the book which was in the field during the day was always needed at night for reducing the readings and completing the notes, so the draftsman either had to be a whole book behind in his work or else the field party must work first in one book and then in another, either of which methods was objectionable.

After the survey had been in progress for a time it was decided that since working maps were needed they could as well be made by the field parties instead of the plotting of the protractor sheets, thus sav-

ing some labor and securing the necessary check on the survey and a complete set of working maps at the same time.

It was desirable to plot the base line on these working maps by latitudes and departures, and, as they must be figured, it became convenient to check the stadia circuits by figuring their latitudes and departures and comparing results with those of the base line at the closing station.

The method pursued thereafter was, therefore, to check the stadia circuits by latitudes and departures immediately when closed; to send a book, when completed, to the headquarters of the survey, where the numerical work contained therein was first checked and the notes then plotted and errors or omissions reported back to the field for correction. The work was so divided among the stadia parties that each party could remain long enough in one locality to fill several books, and it was very seldom that a party had to go back to a previous location to look up errors.

After the winter work on Oneida Lake was completed the force was so large, numbering, as it did for several months, nearly 100 men, and the work was so scattered that it would have been impossible to maintain a thorough control of it if the mapping had not been centralized and reduced to a system as above described.

A record has been kept of the amount of time spent on the different portions of the drafting, from which has been prepared the following statement showing the percentage of the total labor expended on each part:

| | Per cent. |
|---|---|
| Plotting base line, stadia circuits, and triangulation | 5.4 |
| Plotting topography | 39.9 |
| Sketching contours | 12.1 |
| Checking work | 11.3 |
| Inking elevations | 6.1 |
| Inking right lines | 5.4 |
| Inking contours | 4.4 |
| Inking names of property owners | 5.1 |
| Inking conventions, station numbers, and contour elevations | 3.5 |
| Lettering | 3.6 |
| Cleaning | 3.2 |
| Total | 100.0 |

These percentages are based upon the actual time spent upon the work, and have nothing to do with its cost, since the salaries of the men were varied according to skill, experience, and the position which had been held on the survey.

Respectfully submitted.

ALBERT J. HIMES,
*Assistant Engineer.*

THE BOARD OF ENGINEERS ON DEEP WATERWAYS.

## APPENDIX NO. 14.

### OSWEGO-MOHAWK ROUTE, EASTERN DIVISION.

DETROIT, MICH., *October 17, 1899.*

GENTLEMEN: I have the honor to respectfully submit the following report on the Oswego-Mohawk route, generally known as the Oswego route, eastern division, from Herkimer, N. Y., to the Hudson River at Troy, N. Y.

#### INSTRUCTIONS.

Reference is hereto made to Appendix No. 9, "Instructions for survey parties," as issued by the United States Board of Engineers on Deep Waterways, as governing in general the methods of work pursued. As the result of experience obtained as the work advanced, I found certain modifications of detail connected with these instructions advisable on this division, as better adapting themselves to the conditions existing and the work in hand; these, with the methods pursued and results obtained, are herewith referred to in this report.

#### ORGANIZATION.

The field work of this division was actively begun at the Hudson River end of the Oswego route in October, 1897, the first one-half of the month being occupied in the organization of parties and general preparations incident to the beginning of the work.

A level party began work on October 16, a transit party on October 19, one stadia party on October 21, and another on October 28. On December 1, 1897, it was deemed to the best interest of the work to combine the transit and level work under one party, and during the remainder of the survey this combined work was done by the former transit party. On December 1, 1897, a sounding party was organized.

During the first part of December, 1897, the necessary outfit and plant for a boring party was collected, and one party began work on December 21, a second one on January 27, 1898, and a third one about March 1.

This force of three boring parties was continued until the latter part of July, 1898, when two additional parties were added, and on September 19, 1898, a sixth party was organized. This force was continued until the completion of the borings to Herkimer and from Herkimer about 4 miles northwest to Frankfort, on the Oswego route, western division, to which point they were completed on November 18, 1898.

#### METHODS OF WORK, WITH RESULTS OBTAINED.

*Transit work.*—This party was engaged on days unfit for field work in the reduction of notes and computation of coordinates of transit

stations, which were sent in to the office of the assistant engineer as fast as completed.

As a general check on the results of the transit work for long distances connection was made between this work at station 0.0 at the Congress Street Bridge and a New York State triangulation station there. Connection was also made between the transit line and the following New York State triangulation stations along the line by intersections on the same: At Amsterdam, Roman Catholic Church spire; at Canajoharie, Dutch Reformed Church; at Little Falls, Methodist Episcopal Church; at Herkimer, Methodist Episcopal Church. The coordinates of transit stations were carried continuously through the work, corrections being applied as authorized in "Instructions for survey parties."

The "running" error between observations taken ranged from 00′ 35″ to 06′ 20″, and the distances between observations taken from 5.7 to 9.6 miles.[1] A transit line traverse along both banks of the Hudson River from Troy to Waterford showed a "running" error in azimuth of 01′ 30″ and an error in latitude of 0.15 feet and in departure of 0.59 feet. The general direction of this traverse was north and south. Another transit line traverse near here of about 3½ miles showed an error in azimuth of 02′ and in latitude of 3.75 feet and in departure of 3.82 feet.

The following table shows the comparison between the transit work and that of the New York State triangulation. The latter is assumed to be correct, but it must be remembered, in reviewing this comparison, that the coordinates of these triangulation stations are given to the third decimal place in seconds; also that the value of 1″ of latitude, as measured on the meridional arc at 42° of latitude, is about 101 feet, and 1″ of longitude, as measured along the parallel at 42° of latitude, is about 75 feet.

| Place. | | Difference in latitude (New York State survey). | Difference in longitude (New York State survey). | Error in transit line (latitude-longitude). | Proportion of error to distance. |
|---|---|---|---|---|---|
| From— | To— | | | | |
| | | *Feet.* | *Feet.* | *Feet.* | |
| Congress Street Bridge. | Amsterdam | 24 | 29 | 38 | $\frac{1}{5832}$ |
| Do | Herkimer | 46 | 00 | 46 | $\frac{1}{1333}$ |

The proportion of error to distance is obtained by finding the hypothenuse of a right-angled triangle from the latitude and longitude as base and height, respectively, divided into the total distance and expressed as a fraction.

[1] The average running error for 14 observations was: "Running" error 02′ 30″, distance 6.3 miles.

*Level work.*—For the first 20 miles of this work from the Hudson River end Philadelphia level rods were used.

For the remainder of the work, two rods specially made to order were used. These rods were made of white pine, paraffined in about one-fourth of an inch, in one length of 10 feet 7¾ inches over all, reading to 10 feet. They were graduated on the face to feet, tenths, and hundredths, with vernier reading to thousandths. On the back of each rod a round folding plumbing level was attached.

The target was square, 4 inches high by 5½ inches wide, with black enameled face, with a vertical white enamel strip one-fourth inch wide through the center, and two narrow, horizontal white enamel strips, each tapering from the outside edges of the target to the centers, these white strips being one-fourth inch at outside and about one-sixteenth at center.

The target was moved up and down by an endless steel tape one-fourth inch wide, attached to top and bottom of target with screws to regulate tension of the same and passing over pulleys set flush in the rod near the top and bottom. The target vernier was arranged so that it could be pressed down flat on the face of the rod by a spring, enabling more accurate reading of the vernier.

The accompanying sketch shows a front view and cross section of these rods, also the steel pins used for turning points. These were driven firmly in the ground by a wooden mall.

The advantages of the rods and turning points used are, briefly stated, less liability of the rod to change of length through influences of moisture, no risk of rod slipping as in use of sliding rod, exact graduation of the same, no risk from rod being held at different elevation for fore and back sight, and the target arrangement enabling a more exact setting and reading of the same. All of which are essential points for obtaining good results.

Duplicate levels were run in opposite directions and the instrument shaded by an umbrella from the rays of the sun during hot weather. Immediately after the back sight to obtain height of instrument, the forward sight was taken on the next turning point, thus minimizing risk of instrument settling.

The limit of error between duplicate level lines per "Instructions for survey parties," as issued by the United States Board of Engineers on Deep Waterways, was $0.05 \sqrt{\text{distance in miles}}$. The 0.05 in this formula will be referred to as C in the following remarks.

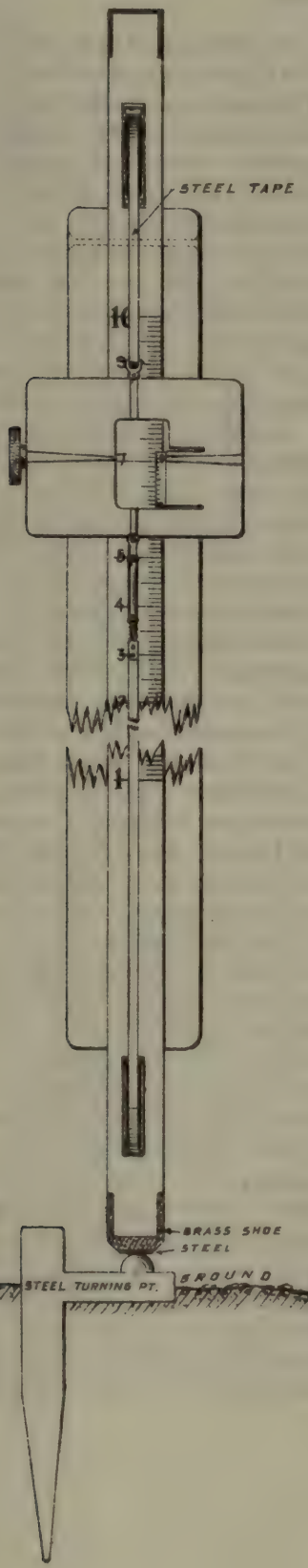
The elevation of 68 bench marks were determined between Congress Street Bridge at Troy, and Herkimer, the distance by the transit line being about 88 miles.

The mean elevation of the two lines, run in opposite directions, was used as the adopted elevation of the bench mark.

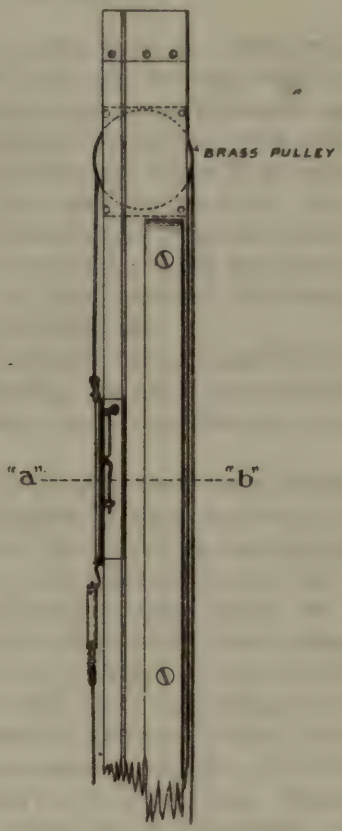
The maximum value obtained of C for lines between consecutive board measurements was 0.035 for 1.66 miles; the minimum, 0.001 for 0.93 miles, and the average, 0.0115 for 88 miles.

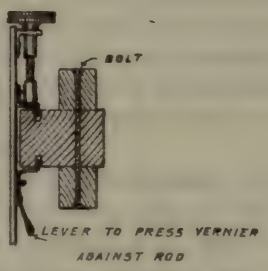
# Level Rod

Front View

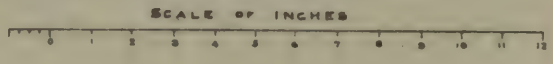



Side View

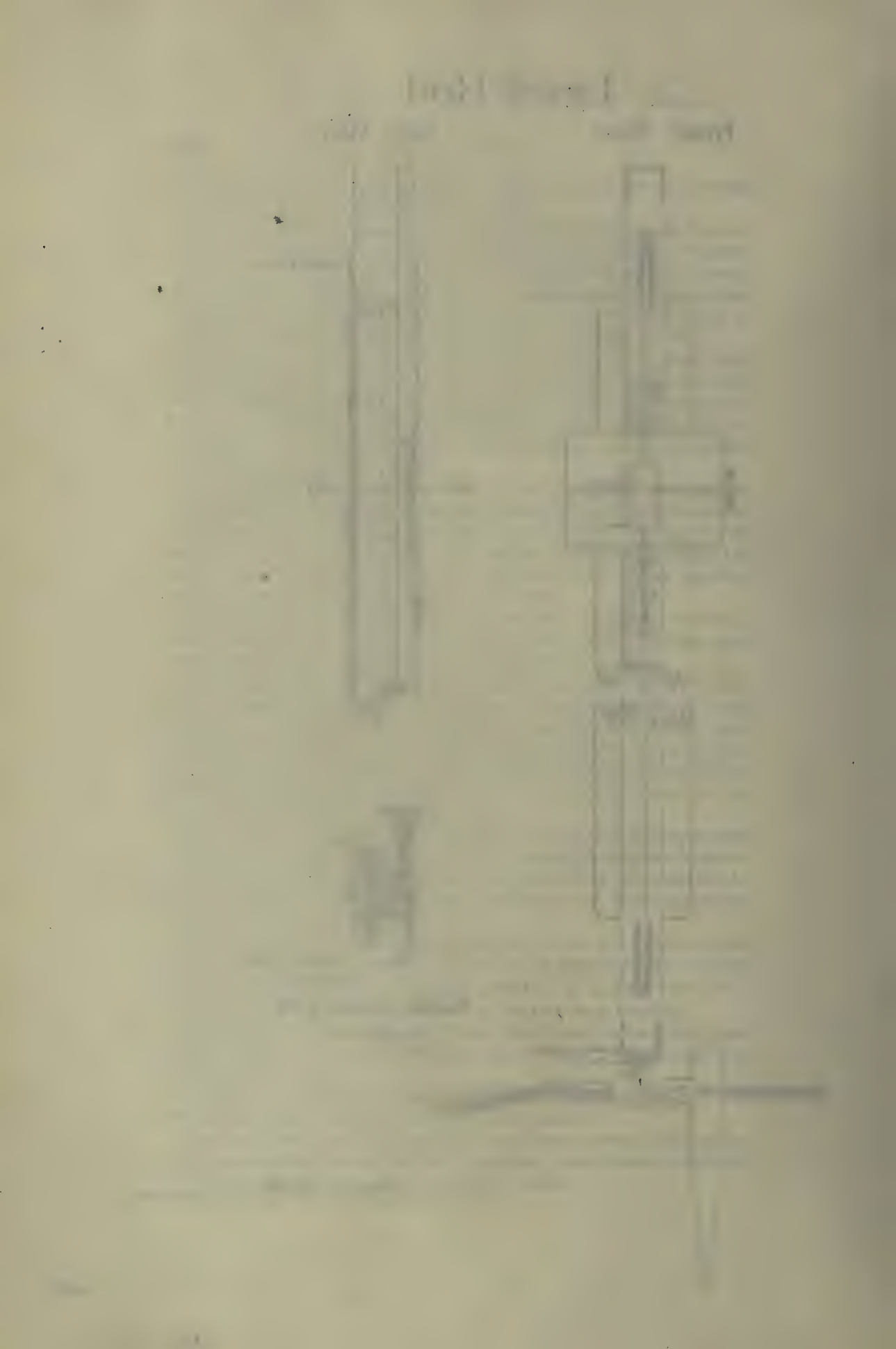



Section on line "a"—"b"




H.T.F.



The maximum value of C for lines from the origin was 0.022 for 18.29 miles; minimum, 0.001 for 5.86 miles; average, 0.009 for 88 miles.

The following values of C were obtained at distances stated from origin. These values being selected at random: 0.018 at 20.81 miles, 0.003 at 39.53 miles, 0.004 at 60.96 miles, 0.002 at 87.86 miles.

Buff & Berger level No. 2652 was used on the work. It is but just to say this line of level was run for the most part over level stretches, following the transit line along railroads, roads, and the Erie Canal towpath, the total difference in level between the origin and the end of line at Herkimer being about 367 feet.

*Stadia work.*—The best and most satisfactory results were obtained on this division under the following organization of a stadia party: One in charge to sketch and direct party, one observer, one recorder, four rodmen or stadiamen.

There are certain advocates of the plan that with a liberal amount of contour points taken and location by shots made of existing features, natural and artificial, the time taken in making sketches in the field is largely time wasted. This supposition, I believe, in actual practice will be found to be theoretically correct only.

My experience convinces me that an absolutely indispensable requisite to a correct representation of the topographic features of a section, when reduced to a drawing, is a full, clear, and complete sketch, not necessarily to scale, of the relative positions of the several points located and the topography intervening, accompanying the notes and made on the ground while the survey is in progress. This statement I mean to apply regardless of the number of shots taken or locations made. Whether the notes are to be platted by the party or parties taking the same, which I believe to be preferable, or by other parties unfamiliar with the locality, the sketch is of inestimable value to a correct interpretation of the notes, however clear they may be.

In actual practice I have found that two intelligent persons engaged on the same survey will, with all the points taken in the field platted on a map, in the absence of sketches, misrepresent, each to a marked degree of difference, the facts as they exist.

A sketch, however crude it may be, is a transmission to paper of the impression of the ground and its features as made on the mind of the observer with the features spread out before him, and is of more value than anything else in recalling these features and correctly drawing them on the maps at some future time. It also acts as a check on the accuracy of the readings for position and elevation. It enables not only those engaged on the survey, but others not familiar with the same, whose duties it may be to plat the notes, to more quickly and accurately draw the maps.

While the governing conditions may not always be such that the notes taken in the field can be platted and drawn by the parties taking the same, yet the nearest approach to this, and the sooner they

can be drawn after being taken in the field, is believed to be the best practice.

The above observations are indulged in as influencing the methods of work as pursued on this division, and also for what use they may be to the engineering profession, and it is this last consideration that may prompt a brief discussion of certain methods, although not wholly pertinent to this report.

In the above organization of a stadia party, the man in charge directed the work and made all sketches of the area being surveyed, being at liberty to follow the rodmen where he deemed it best to more accurately sketch at close range. He identified this sketch with the recorder's notes by similar numbers for shots taken, checking up these numbers with him at intervals.

The observer ran the instrument and took all observations, having a code of signals for each rodman.

The recorder recorded all readings, noting, under remarks, the character of the shot taken—whether a contour point, a fence corner, stream, ditch, river bank, or corner of a building, etc., abbreviations for these being used and an index of the same recorded in the notebooks.

Just here I would state that no recorder, however quick he may be, can with a rapid observer do more than actually record for two or three good rodmen or stadiamen, and at times to do even this he is crowded for time, and his attention is wholly absorbed therewith, to the exclusion of any time to make sketches. He is compelled to remain at the instrument, and, even if time were available, sketches made by him at long range would be useless, as probably misleading instead of aiding. Three rodmen or stadiamen were generally employed in the field, and the fourth one when occasion required. These men briefly noted, when necessary, either in a book or on a slip of paper, on the back of their rods the character of the location held at, or, if covering a section of less importance as to detail or inaccessible to the man sketching, they made a sketch connecting the points taken.

The fourth rodman was employed the greater portion of the time in the office where the temporary headquarters of the party were located.

The map sheets were furnished the stadia parties from the office of the assistant engineer, with the coordinates laid off and the base line platted from these coordinates on the same.

The stadia parties were engaged, on days when the weather prevented fieldwork, in the reduction of notes and platting all shots taken in pencil and drawing in all natural and artificial features, the rodman in the office prosecuting this work alone when the party was in the field. In this way, all office work was kept fairly close up with the fieldwork, and any corrections necessary or additional data needed could be at once supplied.

As soon as these sheets were completed they were sent in to the office of the assistant engineer.

There are those who, generally speaking, have never used, to any great extent, improved stadia methods, who seriously question the accuracy of the same to the extent of its usefulness for surveys of this nature and general preliminary surveys.

It is believed a thorough appreciation of the excellent results attainable with properly graduated rods and ordinary refined methods would lead to its more general adoption, and enable preliminary surveys and examinations for contemplated works to be made at a large saving of time and expense. It is with a view to this that the following results of stadia work, as found on this division, are given.

In the early stages of this work, when the organization was being perfected and the parties trained to the adoption of the best methods for the prevention and elimination of errors, more likely to occur at the beginning of surveys of such an extended nature, the transit line as measured by steel tape and leveled with Y-level, was retraced with a stadia line, each transit station being occupied and a forward and back reading being taken in each case for distance and vertical angle, the mean of the two being taken as the correct result.

These distances and elevations, as obtained by stadia, were carried continuously over the distance given, and offer an interesting and instructive lesson, by direct comparison, as to the excellence attainable by stadia methods, compared with careful transit work with steel tape and Y-levels. About one-half of this line was along the towpath of the Erie Canal, and the other half across country. The work was done in the month of December. I do not believe quite as favorable results could be depended upon if the weather was warm and the air "boiling." The table of comparison follows:

TABLE No. 1.—*Comparison of stadia and base line work deduced from the relocation by stadia of the base line for a distance of 5.6 miles.*

| Station as per transit line. | Station as per stadia line. | Error in distance of stadia line (+ or −). | Azimuth by transit line. | Azimuth by stadia line. | Elevation by level. | Elevation by stadia. | Error of stadia levels (+ or −). |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Feet.* | *Feet.* | ° ′ ″ | ° ′ ″ | *Feet.* | *Feet.* | *Feet.* |
| 162+37.89 | | | | | | | |
| 165+56.68 | 165+56.7 | ..... | 98 16 00 | 98 16 00 | 95.10 | 95.10 | ..... |
| 168+87.92 | 168+89.1 | + 1.2 | 108 34 00 | 108 35 15 | 98.42 | 98.38 | −0.04 |
| 173+26.60 | 173+26.3 | — 0.3 | 167 10 00 | 167 11 15 | 90.32 | 90.31 | −0.01 |
| 182+37.06 | 182+36.3 | — 0.8 | 158 39 30 | 158 40 15 | 104.95 | 104.99 | +0.04 |
| 185+77.10 | 185+76.2 | — 0.9 | 128 12 00 | 128 12 00 | 123.86 | 123.87 | +0.01 |
| 189+53.40 | 189+51.7 | — 1.7 | 155 52 30 | 155 52 15 | 136.52 | 136.60 | +0.08 |
| 200+29.18 | 200+25.6 | — 3.6 | 140 50 30 | 140 50 00 | 142.70 | 142.84 | +0.14 |
| 207+88.34 | 207+84.9 | — 3.4 | 139 11 00 | 139 10 30 | 165.41 | 165.64 | +0.23 |
| 211+64.40 | 211+60.1 | — 4.3 | 123 12 30 | 123 12 00 | 155.63 | 155.84 | +0.21 |
| 217+74.67 | 217+70.7 | — 4.0 | 150 03 30 | 150 03 30 | 154.73 | 154.82 | +0.09 |
| 224+08.30 | 224+03.2 | — 5.1 | 153 43 30 | 153 43 30 | 164.44 | 164.52 | +0.08 |
| 224+80.99 | 224+75.7 | — 5.3 | [1]142 13 00 | 142 09 45 | | | |
| 226+66.60 | 226+62.8 | — 3.8 | [2]186 58 00 | 186 56 00 | 154.50 | 154.57 | +0.01 |
| 230+17.29 | 230+13.8 | — 3.5 | 174 47 30 | 174 46 30 | 154.37 | 154.32 | −0.05 |
| 236+52.67 | 236+47.4 | — 5.3 | 161 46 30 | 161 45 15 | 154.86 | 154.69 | −0.17 |
| 243+06.16 | 243+00.9 | — 5.3 | 170 13 30 | 170 12 00 | 156.02 | 155.78 | −0.24 |
| 253+34.99 | 253+22.0 | —13.0 | 150 18 30 | 150 16 45 | 155.95 | 155.78 | −0.17 |
| 257+58.35 | 257+47.6 | —10.7 | 120 39 30 | 120 37 15 | 190.21 | 190.23 | +0.02 |
| 267+13.73 | 267+00.7 | —13.0 | 159 20 00 | 159 17 30 | 191.85 | 191.69 | −0.16 |
| 270+06.33 | 269+92.2 | —14.1 | [3]139 25 30 | 139 23 15 | 192.86 | 192.31 | −0.55 |

[1] Azimuth start together again from here.
[2] These azimuths are cut out from the base line.
[3] Difference here is due to the base line point being on a snubbing post. Height of instrument estimated.

TABLE No. 1.—*Comparison of stadia and base line work reduced from the relocation by stadia of the base line for a distance of 5.6 miles*—Continued.

| Station as per transit line. | Station as per stadia line. | Error in distance of stadia line (+ or −). | Azimuth by transit line. | Azimuth by stadia line. | Elevation by level. | Elevation by stadia. | Error of stadia levels (+ or −). |
|---|---|---|---|---|---|---|---|
| *Feet.* | *Feet.* | *Feet.* | ° ′ ″ | ° ′ ″ | *Feet.* | *Feet.* | *Feet.* |
| 276+16.07 | 276+01.7 | −14.4 | 120 31 00 | 120 29 00 | 190.99 | 190.90 | −0.09 |
| 284+41.93 | 284+29.1 | −12.8 | 146 01 30 | 145 59 30 | 190.68 | 190.67 | −0.01 |
| 289+68.83 | 289+57.9 | −10.9 | 163 59 30 | 163 58 15 | 190.39 | 190.57 | +0.12 |
| 292+65.18 | 292+54.4 | −10.8 | 136 31 00 | 136 30 30 | 190.33 | 190.26 | −0.07 |
| 297+69.65 | 297+60.2 | − 9.4 | 125 35 30 | 125 34 45 | 190.31 | 190.11 | −0.20 |
| 301+99.41 | 301+90.7 | − 8.7 | 152 07 00 | 152 06 15 | 191.28 | 191.08 | −0.20 |
| 313+10.28 | 313+03.7 | − 8.6 | 183 00 30 | 182 59 45 | 191.22 | 191.25 | +0.03 |
| 322+57.21 | 322+50.9 | − 6.3 | 178 44 00 | 178 43 00 | 191.46 | 191.58 | +0.12 |
| 326+71.22 | 326+63.4 | − 7.8 | 165 37 00 | 165 36 00 | 189.85 | 190.02 | +0.17 |
| 332+04.44 | 331+94.9 | − 9.5 | 144 31 00 | 144 29 45 | 191.81 | 191.95 | +0.14 |
| 342+11.26 | 342+00.0 | −11.3 | 137 27 00 | 137 25 00 | 189.74 | 189.79 | +0.05 |
| 345+84.25 | 345+72.1 | −12.2 | 172 32 30 | 172 30 30 | 190.60 | 190.59 | −0.01 |
| 356+46.47 | 356+32.6 | −13.9 | 179 05 30 | 179 03 00 | 192.10 | 192.07 | −0.03 |
| 361+80.69 | 361+66.3 | −13.4 | 163 35 30 | 163 32 45 | 195.65 | 195.75 | +0.10 |
| 366+33.37 | 366+17.8 | −15.6 | 63 57 00 | 63 54 15 | 183.60 | 183 74 | +0.14 |
| 375+32.27 | 375+17.4 | −14.7 | 78 49 30 | 78 46 45 | 178.56 | 178.50 | −0.06 |
| 378+32.63 | 378+17.5 | −15.1 | 85 52 30 | 85 49 30 | 183.49 | 183.56 | +0.07 |
| 388+44.34 | 388+31.5 | −12.8 | 31 36 30 | 31 33 30 | 192.53 | 192.79 | +0.26 |
| 392+82.07 | 392+68.8 | −13.3 | 26 35 30 | 26 32 15 | 181.46 | 181.72 | +0.26 |
| 404+77.12 | 404+65.1 | −12.0 | 15 01 00 | 14 58 00 | 175.74 | 176.09 | +0.35 |
| 410+88.65 | 410+75.8 | −12.8 | 352 04 00 | 352 01 00 | 179.17 | 179.46 | +0.29 |
| 423+62.13 | 423+47.5 | −14.6 | 28 49 30 | 28 46 45 | 180.20 | 180.59 | +0.39 |
| 427+47.82 | 427+32.3 | −15.5 | 38 18 30 | 38 15 45 | 186.70 | 187.11 | +0.41 |
| 431+88.25 | 431+72.0 | −16.2 | 30 36 30 | 30 34 15 | 178.26 | 178.54 | +0.28 |
| 437+69.49 | 437+52.3 | −17.2 | 44 42 00 | 44 40 15 | 177.05 | 177.36 | +0.31 |
| 441+89.92 | 441+72.6 | −17.3 | 46 49 00 | 46 47 30 | 193.62 | 193.96 | +0.34 |
| 445+82.97 | 445+65.3 | −17.7 | 37 56 30 | 37 55 45 | 215.91 | 216.22 | +0.31 |
| 448+65.65 | 448+47.6 | −18.0 | 43 53 30 | 43 53 15 | 190.60 | 190.95 | +0.35 |
| 454+17.49 | 453+98.7 | −18.8 | 14 02 00 | 14 02 30 | 187.29 | 187.67 | +0.38 |
| 458+17.33 | 457+98.4 | −18.9 | 15 22 15 | 15 23 15 | 178.57 | 179.06 | +0.49 |

A number of stadia circuits were run during the progress of the work along the entire line under many varying conditions as to temperature, wind, and character of ground passed over. To attempt to give a complete list of them, with the varying conditions under which they were run, would consume more time and space than the object in view would justify.

Some of these circuits of various lengths began with and closed back on transit or stadia stations, others beginning with and closing on stadia stations of previous circuits. The general results following are selected at random as samples of the work of this kind.

Sixteen circuits as run by one of the stadia parties during the period from May to October, 1898, gave the following results:

| | |
|---|---|
| Average length of circuits | 12,366 feet. |
| Average number of stations occupied | 17. |
| Average running error in azimuth | 01′ 49″. |
| Average error in elevation | 0.20 foot. |
| Average error in circuit | 1 in 1,783 feet. |
| Maximum error in circuit | 1 in 790 feet. |
| Minimum error in circuit | 1 in 3,400 feet. |

Thirty-five circuits as run by another stadia party between October, 1897, and April, 1898, show:

| | |
|---|---|
| Average length of circuits | 5,356 feet. |
| Average number of stations occupied | 11. |
| Average running error in azimuth | 01′ 32″. |

| | |
|---|---|
| Average error in elevation | 0.47 foot. |
| Average error in circuit | 1 in 1,408 feet. |
| Maximum error in circuit | 1 in 801 feet. |
| Minimum error in circuit | 1 in 4,096 feet. |

Forty-four circuits as run between April and July, 1898, show:

| | |
|---|---|
| Average length of circuits | 7,384 feet. |
| Average number of stations occupied | 12. |
| Average running error in azimuth | 01' 32". |
| Average error in elevation | 0.35 foot. |
| Average error in circuit | 1 in 1,832 feet. |
| Maximum error in circuit | 1 in 760 feet. |
| Minimum error in circuit | 1 in 4,244 feet. |

The above are results of average work under usual conditions met with and can be duplicated under same conditions. Results largely in excess of these as to accuracy of distance were accomplished, but are not given here, as they are not considered fair averages of what can be accomplished. The error in the circuit, as given, is found by dividing the length of the hypothenuse of a right-angle triangle, as obtained from the closing error in latitude and departure, into the length of the stadia portion only of the circuit, the length of transit line, if any, not being included in the length of circuit.

In stadia work it will be found many observers have a "personal error;" that is, a tendency to read all distances either somewhat longer or shorter than they really are.

Very long sights, work done when the air is "boiling" or during high wind, or lines run over areas in which high vertical angles occur, all tend to decrease the accuracy of stadia work, but as all these conditions are met with the results given embody them.

*Soundings.*—Soundings were generally made by stretching a line, tagged at 25-foot intervals, across the river between range stakes set opposite on each bank.

These range stakes were set either by the sounding party in advance of the soundings, or by the stadia parties, as found most convenient. Soundings were taken with a line or rod, depending upon the depth of the water. Where the river was of such width as to render the use of the line impracticable, time soundings or intersections, or a combination of both, were used.

*Borings.*—Three different styles of boring machines were used on this division during the progress of the work, and a fourth one, different from each of the others, for a short time during its last stages.

The first machine used was a "Pierce well-boring machine." Reference is made to the maker's catalogue for a description. The additional machines used were built on this work, except the Sullivan machine. They were in two styles, both of wood, and of cheap construction, but rendered excellent service.

One style was a simple tripod, with pulley at the top and a rope passing over the same, to one end of which either a large wooden

maul was attached for driving the casing, or else the drill rods for washing out the same. With the other end of the rope one or two men raised the maul or drill rods. The other style was in construction similar to a small pile driver, with a base of about 4 feet between foot of leads and brace and extending out about 2½ feet in front of the leads. It was about 15 feet in height, with leads protected by thin iron strips, in which an iron hammer, with a hollow in bottom for wooden cushion, was moved up and down by a rope attached to and passing over an 8-inch pulley at the top.

Another pulley set in a bracket just in front of the leads at the top was used to pass a rope over, to which the drill rods were attached.

The iron hammer weighed on one machine about 160 pounds and on the other about 180 pounds, and was used for driving the casing, the machine being slipped back about 18 inches by a bar when drilling was in progress. The machine was guyed by two ropes attached to the top and fastened to iron pins driven in the ground.

This machine, with all the tools, could be loaded on a two-horse wagon in about fifteen minutes, and could be set up ready for work in about the same time. It rendered effective service, especially when the casing was hard to drive and the holes deep. The casing was 2½ inches in diameter, extra heavy, in lengths of 2½ to 5 feet, with couplings.

Generally, hollow drill rods, three-fourths inch in diameter, in 5 and 10 foot lengths, were used.

Where rock was penetrated or tested, solid steel drill rods 1¼ inches in diameter, in 10-foot lengths, with male and female screw couplings, were used.

Either flat-pointed hydraulic bits with 2-inch blade or X chopping bits were attached to drill rods.

Douglas & Gould force pumps were both used on the work for forcing water from barrels or streams near by to the bottom of the borings through the hollow drill rods as they were churned up and down, the overflow from the casing pipe being caught in buckets and the material, after settlement, preserved in sample bottles for that purpose.

A sample was preserved at each change of material and samples taken dry, when necessary, by forcing down a hollow pipe into the material, the elevation above datum and the depth of each material being recorded on labels on the bottles.

Where extra hard materials or bowlders or cobblestones were encountered and the casing could not be driven, it was raised up 3 or 4 feet, and from one to four sticks of powder let down and fired with a battery to loosen up the same.

In severe winter weather portable houses, about 8 by 12 feet, were used, in which a stove was placed to heat water in times of freezing.

River borings were made by placing either the "Pierce" or a tripod machine on a catamaran anchored in the river.

The casing pipe was pulled either by a long wooden lever and chain, or by screw jacks, depending upon the difficulties encountered.

The moves between borings were made by teams when practicable, or as near to the point as possible.

In numerous instances the machines and outfit had to be carried by hand to places inaccessible to teams. In this case two gangs were doubled up for the moving when necessary.

Two Sullivan machines were used for about one month during the last part of the work, one on land and one on river borings.

The method used with these machines is, briefly speaking, the working down of 2½-inch flush-joint casing pipe by a constant twisting of the same with pipe tongs, and at the same time a liberal use of water forced down through a 1⅞-inch hollow drill rod, which is either pulled up and down by rope over a pulley at the top of a tripod or else by twisting the drill rod with pipe tongs, explosives being used to loosen the material or remove cobblestones or bowlders in the path of the pipe.

One marked advantage in this method is that the casing is kept constantly loose and is easily raised to blast in the hole or pulled when boring is finished.

Two wagon wheels attached to two legs of the tripod are used to wind the rope attached to drill rod on a drum or in moving the machine from place to place.

The force employed with each machine was from 3 to 4 laborers and a foreman, a double team and driver being employed with each machine, or for two machines, as conditions warranted, to haul water where not at hand or to move the plant.

A superintendent of borings had charge of all parties, recording the results of the several borings from the books kept by the foreman, laying out and locating holes where directed, when not done by other parties, and general direction of the work under the assistant engineer.

The varying conditions met with and different kinds of material encountered in a work of this kind render comparisons difficult between the results obtained from different machines and methods, a machine and method well adapted to one locality being comparatively useless in another, and results obtained as to progress made and cost of work on this division can not be taken as a criterion for others.

The following tabulated statement showing depth penetrated in different kinds of material, with total penetration and cost of same per foot, may be of interest. The borings varied in depth from a few feet to a maximum of from 100 to 190 feet. The price per foot includes all items of cost, including plant.

TABLE NO. 2.—*Showing number of borings made, character of material penetrated, with total penetration and average cost per foot.*

| | Test soundings by hand with steel rod in Mohawk River. | Test borings with machine on land and river in Mohawk Valley.[a] | Test borings with machine on cross-country lines and additional borings in Mohawk Valley.[b] | Total. |
|---|---|---|---|---|
| Number of land borings | | 894 | 271 | 1,165 |
| Number of river borings | | 397 | | 397 |
| Number of soundings | 290 | | | 290 |
| Earth | | 7,139 | 472 | 7,611 |
| Sand | 53 | 17,097 | 3,556 | 20,706 |
| Clay | 36 | 3,762 | 6,082 | 9,880 |
| Blue clay | | | 177 | 177 |
| Gravel | 118 | 2,678 | 19 | 2,815 |
| Shale | | 44 | 117 | 161 |
| Hardpan | | 40 | 60 | 100 |
| Quicksand | | 664 | 865 | 1,529 |
| Sand and gravel | 290 | 1,637 | 801 | 2,728 |
| Sand and clay | | 726 | 2,450 | 3,176 |
| Clay and gravel | | | 760 | 760 |
| Sand and shale | | 35 | 227 | 262 |
| Clay and shale | | 900 | 2 | 902 |
| Gravel and stone | | | 105 | 105 |
| Gravel and bowlder | | | 177 | 177 |
| Hardpan and bowlder | | | 87 | 87 |
| Hardpan and stone | | | 36 | 36 |
| Sand and cobble | | | 63 | 63 |
| Gravel and shale | | 292 | | 292 |
| Sand, gravel, and stone | | 22 | 55 | 77 |
| Sand, loam, and mud | 173 | 727 | | 900 |
| Sand, clay, and gravel | | 1,843 | | 1,843 |
| Gravel and cobble | | 33 | 58 | 91 |
| Mud | 417 | | | 417 |
| Rock | | 413 | 213 | 626 |
| Total penetration | 1,087 | 38,052 | 16,382 | 55,521 |

[a] Including part of western division

[b] Including Niskayuna-Albany line via Shakers; Niskayuna-Albany line via Town House Corners; Schenectady-Cedar Hill and Normans Kill lines, Mohawk Valley (boring for lock and dam sites).

| | | |
|---|---|---|
| Average penetration of 290 soundings in Mohawk River (exclusive of depth of water), feet | | 3.7 |
| Average penetration of 1,291 borings in Mohawk Valley | feet.. | 29.5 |
| Average penetration of 271 borings on cross-country lines and for dam and lock sites, feet | | 60.4 |
| Average penetration of 1,562 borings, total on all lines | feet.. | 34.8 |
| Average cost of 55,521 linear feet, total penetration of all borings and soundings | per foot.. | $0.54 |

## OFFICE WORK IN ASSISTANT ENGINEER'S OFFICE.

The office of the assistant engineer was located so as to be convenient and accessible to the several field parties, and was moved from point to point as the work progressed.

The transit line was plotted on the final map sheets from the coordinates as computed and sent in by the transit party, and these sheets then sent out to the stadia parties, by whom they were returned with all points plotted in pencil, with elevations and all data except contours as taken by this party put on them.

They were then inked, the borings and soundings put on, and all data checked in the assistant engineer's office. They were then contoured in pencil and carefully looked over by the head of the stadia party, who made the field sketches before inking and lettering. They

were then gone over by the head draftsman with the notebook in hand and any data in the stadia, boring, or sounding books not on the maps supplied, when they were sent in to the office of the United States Board of Engineers on Deep Waterways in Detroit, completed except titles.

The above method of work was pursued on the Oswego route proper. On the surveys of the Normans Kill route all notes were worked up in the field and the remainder of the office work completed in the Detroit office, as the main portion of the office force was then located there and this arrangement being deemed best under the circumstances.

### OFFICE WORK IN DETROIT OFFICE.

The first work in this office was the projecting of a center line of location for the canal on the completed map sheets by the United States Board of Engineers on Deep Waterways, and the plotting of a profile of the same on which the character of the material along the line and the elevation of the rock surface as indicated by the borings was shown.

Final estimates of quantities were based upon cross-sections plotted generally at 100-foot intervals from the map sheets showing the surface of the ground and elevation of the rock, with the canal prism drawn on the cross-section sheets, and the grade of the bottom of the canal and elevation of the water surface shown thereon.

Preliminary comparative estimates, necessary to determine the values of different routes, were made either from a center-line profile on the basis of level cuttings or else by average surface elevation as taken from the map sheets.

### ROUTES SURVEYED.

The work of this division embraced one main route, known as the Oswego route, eastern division, and three subsidiary or alternative shorter routes from the Mohawk River near Niskayuna and near Schenectady across country to the Hudson River, known respectively as Niskayuna-Albany route, via Shakers; Niskayuna-Albany route via Townhouse Corners and Schenectady-Normans Kill route.

The several routes mentioned above will be considered under their respective headings.

### Oswego Route Proper.

The Oswego route, eastern division proper, begins at Herkimer, N. Y., and follows the general lines of the Mohawk River and its valley to the Hudson River above Troy, N. Y., the only deviations from the general line of the river and valley worthy of note being at Little Falls, N. Y., where the canal location passes along the foot of the bluff to the south of the river; at Rexford Flats, where the sharp rocky point of land between the New York Central Railroad and the

Mohawk River is cut through; at Crescent, where the line cuts across the sharp bend in the river and skirts along the foot of the hill to the south of the Mohawk; at Cohoes Falls, where the line passes along the top of the bluff to the east of the river, and where a flight of six locks is proposed. From the above point the line cuts across the north end of Simmons Island and through about the center of Van Schaicks Island, entering the Hudson about one-fourth of a mile below the Twelfth street bridge, connecting this island with Lansingburg.

*Field work.*—The survey parties, consisting of a transit, level, and two stadia parties, began work, as authorized by the United States Board of Engineers on Deep Waterways, with the mapping of the shore lines of the Hudson River from the Congress street bridge, over the Hudson River at Troy, N. Y., to the bridge connecting Waterford and Lansingburg, N. Y., about 4¼ miles above the Congress street bridge; also the several branches of the Mohawk River entering the Hudson, with the immediate country adjacent thereto, including all of Green Island, a portion of Van Schaicks and Peobles Island, and of Cohoes and West Troy, lying between the Erie Canal and the Mohawk River.

The soundings proper began at the Cohoes Company's dam above Cohoes Falls, the work below this point being done by the stadia parties.

The boring parties began at the entrance of the South Branch of the Mohawk into the Hudson. The transit work was begun in October, 1897, and completed in September, 1898. The level work was begun in October, 1897, and completed in October, 1898.

The stadia work was begun in October, 1897, one party completing its work in October, 1898, and the other party early in November, 1898. The work of soundings was begun in December, 1897, and completed in October, 1898.

The borings were begun in the latter part of December, 1897, and completed to Herkimer about the 1st of November, 1898, and to Frankfort about the middle of November, 1898.

All work was prosecuted continuously from its commencement to its final completion. The distance alone the Canal Center line from junction with Hudson River line to Washington street, Herkimer, is 83.67 miles. Number of square miles of mainland and islands mapped on this route, 54; number of square miles of river, 9.30; total number of square miles mapped, 63.30. Area of Normans Kill line is 11.95 square miles, making total area 75.25 square miles for the eastern division.

*Reduction of field notes and map work.*—The reduction of all field notes of this route was kept close up with the work by the field parties, and also the plotting in pencil on the final map sheets of all data, ready for inking and contouring in the office of the assistant engi-

neer. The scale of the maps of this route was 1 to 2500 (except through Little Falls, when the scale was 1 to 1000) and contour intervals 2 feet.

The 90 map sheets, embracing the total area mapped on this route, were completed, excepting titles, in the field office at Little Falls, N. Y., on February 14, and the necessary office force for the work of plotting profiles and cross sections and the making of estimates of cost of the proposed ship canal were transferred to the main office at Detroit, Mich.

ARTIFICIAL FEATURES.

The Mohawk Valley, from Herkimer to the Hudson, is a narrow, fertile valley, ranging in width from one-half to 3 miles, the average width, however, not exceeding three-fourths of a mile.

*Railroads.*—The four-track New York Central Railroad follows along the north side of the valley from Herkimer to about 1½ miles below Hoffmanns Ferry, where it leaves the immediate valley, passing to the north of the same, and crosses the Mohawk at Schenectady, going southeast to Albany, N. Y. The West Shore Railroad, double track, follows along the south side of the valley from Herkimer to about 3 miles above Schenectady, whence it bears off southward across country toward the Hudson River. The Fitchburg Railroad, single track, crosses the Mohawk about 5 miles above Schenectady, forming a junction with the West Shore Railroad at Rotterdam Junction. The Schenectady Branch of the Delaware and Hudson Railroad, single track, crosses the Mohawk about 1¼ miles below Schenectady, going west toward South Schenectady. The Troy and Schenectady Branch of the New York Central Railroad, single track, from Schenectady, passes along the side hills and the top of the high bluffs to the south of the Mohawk and well above the same to about 3 miles below Rexford Flats, where it descends into the valley of the river, and passes through the same along the foothills to the south to about 2 miles below Niskayuna, where it again leaves the valley and rises to an elevation of about 160 feet above the river at Crescent station; then descends toward Cohoes, and crosses the South Branch of the Mohawk and the Hudson, entering Troy, N. Y., about one-half mile above the Congress street bridge.

The Saratoga and Champlain Branch of the Delaware and Hudson from Albany, single track, crosses the Mohawk just above the State dam in the Mohawk, where the river separates into its several branches before its confluence with the Hudson River, and extends northward up the Hudson Valley. The Saratoga and Champlain Branch of the Delaware and Hudson from Troy, single track, crosses the canal location on the east side of Van Schaicks Island just before its entrance into the Hudson River.

*Existing canals.*—The Erie Canal from Herkimer eastward passes along the south side of the valley between the Mohawk River and the

West Shore Railroad, descending with the river by a series of locks. It passes along the foot of the Rock Cliffs to the south of the Mohawk at Little Falls and crosses beneath the West Shore Railroad about 1 mile above Fort Plain, thence through Fort Plain to the south of the West Shore Railroad, and crosses the same again about one-half mile below. From here it follows along the south side of the valley, passing through Canajoharie and Fultonville and crossing Schoharie Creek by an aqueduct at Fort Hunter, thence through that part of the city of Amsterdam to the south of the river, and through the bottom land above Schenectady, and through this city to Rexford Flats. Here the canal crosses from the south to the north side of the Mohawk by an aqueduct, thence continuing along the north side of the valley to Crescent, where the canal again crosses the Mohawk by an aqueduct to the north side, and follows down this side and through the city of Cohoes, descending into the Hudson at West Troy, just above the Congress street bridge.

*Dams.*—The first dams encountered in the Mohawk on this division are at Little Falls, N. Y., where three dams cross the river. The first of these, known as the New York State Dam, is at the west end of the city of Little Falls. This dam is in two parts, separated by Lock Island. It is of stone, about 6 feet in height, and has a total crest length of about 700 feet. Elevation of crest above datum, 363. On the south side of the river this dam diverts water for hydraulic power to a portion of the manufacturing industries located there, and also for the canal feeder, some 2,500 feet in length, entering the Erie Canal just below Lock No. 39.

On the north side of the river, power is supplied to the large 3-story knitting mill facing on the river bank.

The second or middle dam, located about one-fourth mile below the above-mentioned one, and known as the Mill Owners' Dam, is a curved dam of cut stone, about 10 feet in height and with a crest length of about 370 feet. Elevation of crest, 356. On the south side of the river, power for hydraulic purposes is diverted by this dam for the manufactories located along the river to the South Ann Street Bridge, which crosses the Mohawk about 1,000 feet below the dam. On the north side, power is supplied to the large number of industries as far east as the William Street Bridge, which is some 2,300 feet below the dam.

The third and last dam here is about one-half mile below the Mill Owners' Dam, and is known as the Gilbert Dam. It is a stone dam, about 9 feet in height, slightly curved, and with a crest of about 170 feet. Elevation of crest, 333.7. It diverts power for hydraulic purposes for the Astoronga knitting mill, on the south side of the river, and for the Little Falls Paper Company, on the north side of the river.

The fourth dam in the Mohawk, just below Indian Castle, on the West Shore Railroad, and about 4 miles below Little Falls, is a

stone dam about 5 feet in height, and with a crest length of about 360 feet; elevation of crest, 319.2. Elevation of top of flash-boards, 321.2. It serves to impound water in the Mohawk and supply the Erie Canal by a feeder known as the Rocky Rift feeder, some 4 miles in length, which enters the Erie Canal just below Lock No. 34, at Mindenville.

The fifth dam in the Mohawk is about 3½ miles below Schenectady and about 800 feet above the aqueduct that carries the Erie Canal over the Mohawk at Rexford Flats. This is a stone dam about 5 feet in height, and a crest of about 670 feet. Elevation of crest, 209.7. It serves to supply the Erie Canal feeder at this place, some 1,900 feet in length, which enters the canal just below Lock No. 21.

The sixth dam is the West Troy Water Company's dam, about 3 miles above Crescent. This is a stone dam about 4 feet in height, separated into two parts by a rocky island. The upper or north dam, at the head of the island, has a crest length of about 380 feet, and an elevation of 174.2; the lower or south dam, at the foot of the island, has a crest length of about 290 feet and an elevation of 173.5. It serves to impound the river, from which a pumping station, located at this dam, pumps water to the reservoirs supplying West Troy, N. Y.

The seventh dam is the Cohoes Company's dam, located about one-half mile above Cohoes Falls. This is a stone dam about 8 feet high, and with a crest from the gate-house to its north end of about 1,330 feet. Elevation of crest of masonry is 152.4, and of the flash-boards 154.2. The present dam was built in 1865, and its construction enables the converting, at low water, of the entire supply of the Mohawk into the hydraulic canal of the company, leading from the dam to the city of Cohoes, and from which the greater portion, if not all, the large manufactories in Cohoes are supplied with power.

About one-half mile below the above dam is situated Cohoes Falls, where there is an almost perpendicular fall in the Mohawk of some 60 feet, the total fall from the foot of the Cohoes Company's dam to the foot of Cohoes Falls being about 84 feet.

The eighth and last dam on the Oswego route, eastern division, before the proposed canal location enters the Hudson, is the State dam opposite the city of Cohoes.

This is a stone dam about 9 feet in height and with a crest of about 1,530 feet. Elevation of crest, 48.9. It was constructed to enable the boats on the Champlain Canal to cross the Mohawk, and also serves to divert water for hydraulic purposes for some industries on the south side of the Mohawk.

*Bridges, aqueducts, and ferries.*—From Herkimer to where the Normans Kill location leaves the Mohawk at Rotterdam Junction, 12 highway and 2 railroad bridges span the river. One of these railroad bridges, below Hoffmans Ferry, now in course of construction, is pro-

posed to carry the tracks of the West Shore Railroad to a connection with the New York Central; and the other, at Rotterdam Junction, carries the single track of the Fitchburg Railroad. Three of the above highway bridges at Little Falls and the railroad bridge at Rotterdam Junction will be undisturbed by the canal location as planned. The old stone aqueduct at Little Falls will also be untouched. It was formerly used to convey water across the river as a feeder for the Erie Canal. It is now unused and partly destroyed. From Schenectady to the Hudson River via the Mohawk River there are 7 highway bridges, 3 railroad bridges, and 2 stone aqueducts over the river. The railroad bridge at Schenectady carries the four tracks of the New York Central Railroad. The one at Mohawk, and also at Cohoes, carries the single track of the Delaware and Hudson Railroad.

The aqueducts at Rexford Flats and Crescent carry the Erie Canal over the Mohawk. The only one of the above structures undisturbed by the canal location is the Crescent Aqueduct.

TABLE NO. 3.—*Existing bridges, aqueducts, and ferries over Mohawk River from Herkimer to divergence of Normans Kill line.*

| Location. | Character of crossing. | Description. | Spans. Number. | Spans. Length. | Total span. | Width between centers. | Height of truss. | Number of piers. | Number of abutments. | Kind of piers and abutments. | Elevation of floor. | Elevation lower chord. | Total width, including sidewalks, etc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Feet.* | *Feet.* | *Feet.* | *Feet.* | | | | *Feet.* | *Feet.* | *Feet.* |
| Herkimer | Highway | South, Pratt truss, steel | 1 | 153 | 153 | 18 | 24 | | 2 | Broken ashlar | 396.1 | 391.5 | (?) |
| | | Bowstring, iron | 2 | 75 | 150 | 18 | 8 | 3 | 2 | Random range | 396.1 | 391.5 | |
| | | Warren girder, iron | 2 | 74 | 148 | 18 | 8 | | | | | | |
| Little Falls: | | | | | | | | | | | | | |
| Hansen avenue south. | do | Through double intersection triangular truss. | 2 | 119 | 238 | 15.5 | 20 | | 2 | Heavy rubble | 378.6 | 375.6 | 22 |
| Hansen avenue north. | do | Double intersection Warren truss, through. | 1 | 133 | 133 | | 20 | 1 | 2 | do | 375.4 | 373.7 | 27 |
| Ann street | do | Pratt truss, curved upper chord. | 1 | 148 | 148 | 31 | 30 | | 2 | Ashlar masonry | 361.6 | 355.6 | 53 |
| Ann street | Old aqueduct. | Stone, unused and partly destroyed. | | | 370 | | | | | | 356.6 | | |
| Little Falls, Seeleys Island. | Highway | Through triple intersection, Warren truss. | 1 | 205 | | 17 | 26 | | | Range masonry | 354.8 | | 28 |
| Little Falls, 2 miles below. | do | Wire suspension, wooden towers. | 1 | 472 | 472 | 11 | | | 2 | Rubble masonry | | 338.7 | (?) |
| St. Johnsville | do | Pratt truss, steel, through | 2 | 216 | 432 | 27 | 35 | 1 | 2 | Cut stone | 325 | 320.4 | 27 |
| Fort Plain | do | Pratt truss, through, curved upper chord. | 1 | 332 | 332 | 22 | 45 | | 2 | Cut stone, first-class. | 318 | 314.1 | 34 |
| Palatine bridge to Canajoharie. | do | Wooden covered bridge | 2 | 107¼ | 540 | 22 | 20 | 3 | 4 | Cut stone | 314 | 311.1 | 30 |
| | | 2 iron bowstring trusses | 1 | 142¼ | | | | | | | | | |
| | | 2 wooden bowstring trusses | 1 | 123 | | | | | | | | | |
| | | 1 wooden Warren truss | 1 | 60 | | | | | | | | | |
| Sprakers Ferry | Ferry | | | | | | | | | | | | |
| Fultonville Fonda | Highway | Bowstring truss | 3 | 122 | 379 | 18 | 17 | 2 | 2 | Cut stone | 297.5 | 295.9 | 24 |
| Fort Hunter | do | Suspension, wire, wooden towers 50 feet high, 2 wooden Warren trusses. | 1 | 537 | 537 | a 11 | | | 2 | Dry masonry | 291.5 | 289.5 | (?) |
| Amsterdam | do | Through, iron truss | 1 | 125 | 407 | 23 | 25 | 2 | 2 | Course and cut stone. | 279 | 276 | 34 |
| | | | 1 | 129 | | | | | | | | | |
| | | | 1 | 153 | | | | | | | | | |
| Hoffmans | Ferry | | | | | | | | | | | | |
| Do | Railroad | Howe truss | 4 | 152 | 741 | (?) | 22 | 5 | 2 | Cut stone | 281 ± | 258 ± | (?) |
| | | Deck | 2 | 61 | | | | | | | | | |
| Rotterdam | do | Pratt, through truss | 4 | 155 | 620 | 16 | 24 | 3 | 2 | do | 254.5 | | 16 |
| Schenectady | Highway | Through pony Pratt truss | 4 | 105 | | 23 | 9 | 7 | 2 | Coursed masonry | 231 | 229 | 29 |
| | | | 2 | 92 | | | | | | | | | |
| | | | 2 | 83 | | | | | | | | | |

*a* Road.

TABLE NO. 3.—*Existing bridges, aqueducts, and ferries over Mohawk River from Herkimer to divergence of Normans Kill line*—Continued.

| Location. | Character of crossing. | Description. | Spans. Number. | Spans. Length. | Total span. | Width between centers. | Height of truss. | Number of piers. | Number of abutments. | Kind of piers and abutments. | Elevation of floor. | Elevation lower chord. | Total width, including sidewalks, etc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | *Feet.* | *Feet.* | *Feet.* | *Feet.* | | | | *Feet.* | *Feet.* | *Feet.* |
| Schenectady | Railroad | Deck; tracks 1, 3, and 4, supported by 6 Warren trusses (double intersection); track 2, by 2 double intersection Pratt trusses. | 10 | 72 | 716 | *a* 6 | *a* 9 | 9 | 2 | Coursed cut stone. | 240 | 230 | 43 |
| Mohawk | Highway | Through Warren double intersection truss. | 4 | 105 | 420 | *b* 11<br>19 | *b* 9<br>17 | 3 | 2 | do | 229 | 227 | 19 |
| Do | Railroad | Deck; 3 double intersection trusses. | 5 | 103 | 515 | *c* 12 | 12 | 4 | 2 | Cut stone (first-class). | 244 | 230 | 12 |
| Rexford Flats | Highway | Through, pony Pratt truss | 7 | 88 | 616 | 20 | 10 | 6 | 2 | Cut stone | 225 | 222 | 20 |
| Do | Aqueduct | 14 masonry arches, wooden trough. | 14<br>44 | Arches, c. c. | 612 | | | 13 | 2 | Coursed cut stone. | 233 | | 60 |
| Vischer Ferry | Ferry | | | | | | | | | | | | |
| Forts Ferry | do | | | | | | | | | | | | |
| Dunsbach Ferry | Highway | Through Baltimore trusses | 3 | 205 | 615 | 21 | 30 | *d* 2 | 2 | Cut stone | 185.7 | 182.2 | (?) |
| Crescent | do | Through pony Pratt truss | 13 | 88 | 1,144 | 18.5 | 7 | 12 | 2 | do | 190 | 188 | 18.5 |
| | Aqueduct | 26 masonry arches, west side; steel truss, east side. | 26<br>44 | Arches, c. c. | 1,144 | | 13 | 25 | 2 | Coursed cut stone. | 191.5 | | 60 |
| Cohoes-Waterford | Railroad | 3 quadruple intersection Warren trusses. | 6 | 154 | 946 | *d* 14 | 24 | 6 | 2 | do | 94 | 91.3 | 14 |
| Do | Highway | Through triple intersection Warren trusses. | 5 | 141 | 705 | 23 | 24 | 4 | 2 | Cut stone coursed. | 67.5 | 64 | 39 |
| Cohoes-Van Schaiks Island | do | 2 through pony Pratt truss<br>Deck-Warren lattice girder | 2 | 75 | 150 | 22 | 10<br>8 | 1 | 2 | Cut stone | 45 | 44.1 | 33 |

*a* Warrens. *b* Pratts. *c* Extremes. *d* Steel.

PHYSICAL CHARACTERISTICS.

*Material—From Herkimer to about 1¼ miles east (Station 4790 to 4850).*—The borings for this section indicate no rock within a depth of 45 or 50 feet below the surface of the valley. The material for this distance is an alluvial deposit of soil varying in depth from 5 to 10 feet, underlaid with fine sand, in places mixed with gravel. Soundings taken with a rod indicate gravel in river bed.

*From Station 4850 to 5115 at the upper end of Little Falls.*—The first rock on this division is encountered in this distance. It varies in depth below the surface from 15 to 35 feet, and is overlaid for the most part with sand, this sand in places being mixed with blue clay with the usual deposit on top of rich loam about 8 feet in depth. Soundings in the river indicate sand and gravel. This is a hard rock, similar in places to that at Little Falls. It outcrops horizontally in places along the south side of the Erie Canal and West Shore Railroad.

*From Station 5115 to 5175 through the city of Little Falls.*—This material is all a hard quartzite rock outcropping, along the canal location, for almost the entire distance and also over the section adjacent to the canal and in the river bed.

*From Station 5175 to 5260, the latter being about three-fourths of a mile below the suspension bridge below Little Falls.*—The borings indicated no rock in the river bed within a depth of 40 feet below the water surface. The material in the bed of the river for this distance is all sand. Steep, rocky cliffs rise almost perpendicularly along this distance, a short distance back from the river bank, as far east as the suspension bridge, where the gorge opens abruptly into the river bottom some three-fourths of a mile in width.

*From Station 5260 to 5650, the latter being at St. Johnsville.*—The surface of the rock, as indicated by the borings, ranged in depth from 10 to 25 feet below the surface of the bottom land, with the exception of just opposite East Canada Creek, where one boring developed no rock at 45 feet below the surface, and also two borings about one-half mile above St. Johnsville, where no rock was encountered at a depth of 50 feet below the surface. This rock outcrops in Castle Creek at the crossing of the West Shore Railroad, and also in places along the line of this railroad for the above distance.

Judging from these outcrops and also from the excavation made for the Rocky Rift feeder for the Erie Canal, the indications are the character of the rock for this distance is a soft shale or slate rock bedded horizontally in thin layers.

The material overlying this rock is sand for almost the entire distance, with occasional pockets of gravel and about 5 to 10 feet of soil. The bed of the river is sand, gravel, and cobblestones, as indicated by the soundings.

*From St. Johnsville to Canajoharie.*—Rock was encountered in the borings for the entire distance at a depth varying from 20 to 30 feet

below the bottom land. The surface of the rock is fairly level. It outcrops in various places along both sides of the valley, generally in horizontal ledges. Occasional outcrops of slate show on the north side of the valley, but the general indications are that the rock along this section is a hard limestone rock. There is a large quarry now in active operation about 1 mile above Palatine Bridge on the north side of the valley, at which stone suitable for dams, locks, and other masonry structures is now being quarried.

Sand overlies the rock the greater part of this distance. In places it is mixed with gravel, and just above the entrance of Garoga Creek (Station 5820) for a distance of about one-half mile blue clay is encountered to a depth of about 25 feet above the rock surface. There is a depth of about 8 feet of soil along most of this section. The river bed is sand, gravel, and cobblestones.

*From Canajoharie to Fultonville.*—Rock was only found at a few places, and at these at a depth of from 30 to 50 feet below the bottom land, except just opposite the "Little Nose," it outcrops on the south shore of the river, but dips down again to the east and west.

The average depths of the borings along this and other sections was 30 feet below the river bed, unless rock was encountered at a less depth or increased penetration necessary for determining foundations for structures.

Limestone rock outcrops in horizontal layers in numerous places along this section on both sides of the valley as far east as "The Noses."

About 1½ miles above Yatesville two prominent limestone cliffs rise several hundred feet almost perpendicularly from the valley, the one on the north side being known as the "Little Nose" and the one on the south side as the "Big Nose." From "The Noses" to Fultonville soft shale rock outcrops along the south side of the valley, and is especially noticeable along the Erie Canal and West Shore Railroad above Fultonville.

The character of the material between Canajoharie and Fultonville is mostly sand, in a few cases mixed with clay and gravel, the usual deposit of soil overlying this material to a depth of about 10 feet. The bed of the river for this distance is mostly sand and gravel, with some cobblestones.

*From Fultonville to about 1 mile below Schenectady (Station 8131).*—For this distance rock was encountered at only a few isolated places worthy of mention, namely, about 1½ miles below Fultonville, for a distance of about 2,500 feet, at a depth of 25 feet below the river bed; about 3½ miles below Fultonville, for a distance of 3,000 feet, at a depth ranging from 15 to 35 feet below the bottom land; at Fort Hunter, for a distance of about 1,000 feet, at a depth of about 25 feet below the river bed; just above Amsterdam, for a distance of about 3,000 feet, at a depth of from 10 to 40 feet below the river bed; at Cranesville, just at the head of the lock there, at a depth of about 60

feet below the river bed; and about 3½ miles above Schenectady, for a distance of about 2,000 feet, at a depth of 5 to 25 feet below the river bed.

Occasional outcrops indicate the existence of soft shale as far east from Fultonville as Fort Hunter. From Fort Hunter to about 1½ miles above Hoffmanns Ferry the evidence is that hard limestone rock exists in horizontal ledges of from 1 to 6 feet in thickness. Outcrops and exposed quarry faces at Fort Hunter on the north side of the river indicate this, also at Amsterdam along the north shore of river and in cuts along the West Shore Railroad on the south side as far east as 1½ miles above Hoffmanns, also in the beds of several small streams on the north side of the river. No outcrops of rock were noticed for about 1½ miles above Hoffmanns to about three-fourths of a mile below the Fitchburg Bridge, where slate rock outcrops in the bed of a small stream (opposite station 7864), also in bed of Erie Canal (opposite station 7911), also opposite station 7936; soft shale outcrops along banks of canal.

The borings and soundings taken over this distance indicate about 10 to 15 feet of soil along the valley. Sand generally underlies the soil, with occasional pockets of gravel and gravel and sand mixed. Blue clay, for the most part tough, is found under the sand in isolated places at depths of from 10 to 15 feet below the river bed. The sand and gravel is in places stratified with blue clay.

Quicksand was only encountered in a few borings.

From the Fitchburg Bridge at Rotterdam Junction for about 2 miles east sand mixed with large gravel and cobblestones was found. Blue clay and gravel, where found mixed, was hard and required the frequent use of explosives to penetrate. From about one-half mile above Fultonville to about 3 miles above Schenectady the river bed is, for the most part, large and small bowlders mixed with cobblestones, although this condition is perhaps more pronounced between Fultonville and Cranesville than below the latter place. Strata of hard cemented gravel about 6 to 8 feet in thickness crops out along the north bank of the river well above the water level about 2 miles above Schenectady (station 7986). This same material was encountered in two borings on the same side of the river, about one-half mile below the above point. It also outcrops along the steep bank to the north of the river opposite Rotterdam Junction.

*From about 1 mile below Schenectady to Hudson River.*—This division may be designated as the rock section of this route, as shale rock is characteristic for almost the entire distance.

From the highway bridge over the river about 1 mile below Schenectady for a distance of about 1 mile going east the bed of the river is practically all rock, but it then dips down for a distance of about three-fourths of a mile, and no rock was found at a depth of 25 feet below the river bed.

The surface of the rock, however, immediately rises to the river bed and continues with the same as far east as about opposite Niskayuna.

From Niskayuna to Vischer Ferry borings in the flat bottom lands, across which the canal location passes, developed no rock at a depth of 65 feet below the surface.

From Vischer Ferry to where the canal location enters the Hudson the bed of the river is practically all rock, at places developing a very irregular profile.

The banks of the river in places along this section, especially below Rexford Flats and from Crescent to Cohoes, are perpendicular cliffs of soft shale rock. The section adjacent to the river is also for the most part similar material.

Where there is a deposit on the rock it is generally sand and gravel mixed. In the flat bottom land opposite Niskayuna, to the north of the river, black loam covers the surface to a depth of 10 to 15 feet, underlaid by sand and blue clay, in places stratified.

### SUMMARY.

A summary of the material from Herkimer to the Hudson River, via the Mohawk, from information at hand, combined with the preliminary geological map as issued by the State of New York, developed the fact that from Herkimer to the Suspension Bridge below Little Falls the rock is hard. At Little Falls it is a quartzite, designated on the geological map of the State as "Laurentian granite," blending to the west into "Calciferous sand rock," and to the east into the "Hudson River and Utica formations."

From the Suspension Bridge to St. Johnsville the rock is apparently a soft shale or slate rock. From St. Johnsville to Fultonville the rock is for most part a hard limestone, and exists in large quantities. The geological map of the State indicates the existence of Trenton limestone to the south of the river below St. Johnsville, and Calciferous sand rock on the north side, the latter extending down the valley to Sprakers, where a small area of Laurentian granite exists to the north of the river. From the above point the rock blends into the Hudson River and Utica formations toward Fultonville.

From the above point to Fort Hunter the small amount of rock found is shale rock. From Fort Hunter to above Hoffmanns Ferry hard limestone rock is found. The State geological maps show Calciferous sand rock for most of this distance, with small area of Trenton limestone at Tribes Hill and Fonda.

From above Hoffmanns Ferry to the Hudson, shale rock, generally soft, is found, designated on the State geological map as Hudson River and Utica formation.

The limestone and quartzite rock as found along the above route is suitable for concrete, retaining and slope walls.

Sand and gravel exist at various places for the preparation of concrete, and probably clay, suitable and in sufficient quantities for all puddling needed.

*Water courses.*—The principal water courses entering the valley along this division are West Canada Creek, just below Herkimer; Indian Castle Creek; East Canada Creek, about 6 miles below Little Falls; Garoga Creek, about 2½ miles above Fort Plain; Otsquaga Creek, at Fort Plain; Canajoharie Creek; Flat Creek, at Sprakers; Cayadutta Creek, at Fonda; Schoharie Creek, at Fort Hunter; North and South Chuctenunda Creek, at Amsterdam; Alplaus Kill, above Rexford Flats; and Stony Creek, at Vischer Ferry. The drainage area of the above water courses and their flood discharges will be discussed in Appendix No. 16.

*High-water marks.*—The only stationary gauge readings recorded on this division were at the West Troy Company's dam. This gauge was located just above the lower dam on the south side of the river, and continuous readings were taken by the man in charge of the pumping station located there from March 12, 1898, to March 31, 1899.

The elevation of the crest of this lower dam above datum is 173.5.

The highest reading recorded was on March 14, 1898, elevation 180.7, and the lowest on July 25, 1898, elevation 171.4. The ice moved out of the river on March 7, 1898, and a high-water elevation of 186.2 was noted at Vischer Ferry by the sounding party. The river was then open to the Hudson.

Two openings existed in the West Troy Company's dam at the time this gage was located there—one near the south bank about 23 feet long by 20 inches deep below the coping; another near the center of the dam about 51 feet long and from 3 to 8 feet deep; the sectional area of the two openings being about 380 square feet.

Other temporary gauges were read at different points along the work by the several parties between March and December, 1898, and simultaneous water levels were taken at various points between the West Troy Company's dam and Herkimer, to determine the slopes in the river.

The water surface was about 2 feet above its lowest stage when these readings were taken. The following high and low water marks were observed, all with reference to datum:

| | High water. | Low water. |
|---|---|---|
| Schenectady | 217.4 | 210.2 |
| Hoffmans Ferry | 240.7 | 236.6 |
| Fort Hunter | 272.4 | 26..1 |
| Fultonville | 282.6 | 273.6 |
| Canajoharie | 289.0 | 284.6 |
| Fort Plain | 299.4 | 291.8 |
| St. Johnsville | 304.8 | 299.3 |
| Little Falls, below the dams | 325.9 | 321.2 |
| Little Falls, upper dam | 304.5 | 365.8 |
| Herkimer | 376.0 | 374.8 |

The high-water mark of 282.6 at Fultonville occurred while the assistant engineer's office was located there, and was regarded as very exceptional.

Certain information was obtained along the valley as to flood heights at different times during past years. On a house on the river bank, just above the Cohoes Company's dam, high water on March 16, 1889, is said to have been at elevation 161.9, and an ice freshet in the spring of 1868, elevation 165.9.

The crest of the masonry of this dam is 152.4. A high-water mark is given at Crescent, on the house of H. L. Haights, due to ice freshet in spring of 1868, elevation 179.0.

Ordinary spring freshets here attain an elevation of about 174.0.

The bed of the river below the aqueduct is rock and about elevation 161. At Dunsbach Ferry an ice gorge in 1893 is said to have raised the water to elevation 181. The ordinary spring freshets attain an elevation of 175. The elevation of the lower chord of the bridge here is about 182. At Forts Ferry a flood elevation is given of 185.4.

At the railroad station at Niskayuna a high-water mark of elevation 187.9 is given.

Ordinary spring floods reach elevation 180. The railroad track here is elevation 195. At the Delaware and Hudson bridge below Schenectady a high-water mark is given of elevation 222.9.

The base of rail on this bridge is about elevation 229.

At Canajoharie a high-water mark, due to ice gorge in spring of 1890, is given on end of stone wall at New York Central Railroad station, elevation 304. The railroad track here is elevation 300. At Fort Plain a high-water mark, due to ice gorge February 26, 1891, is given at corner of Willet and Lincoln streets, elevation 310.6. The West Shore Railroad track at station here is elevation 309. About 3 miles above Fort Plain, due to ice gorge in 1865, water was over New York Central Railroad tracks; elevation of tracks, 314. At East Creek Station, on New York Central Railroad, where East Canada Creek crosses the railroad, a high-water mark was given by the station agent, which occurred in 1896, due to ice breaking up in the spring, elevation 329. The railroad track here is elevation 332.

At Little Falls high-water marks are recorded in the planing mill of Andrew Little, located on the north bank of the river, just below the Mill Owners' dam. Mr. George F. Ransom, who has been employed in this mill for over thirty-five years, informed me that the highest water known here was on the 17th of March, 1865, when the water was 4 feet deep on the floor of this planing mill, or, in other words, according to our datum, at an elevation of 361. This flood resulted from the rapid melting of the snow and from the fact that there was at the time about 30 inches of ice in the river, which backed up and formed an ice gorge about where the old stone archway is now located, which was formerly used as an aqueduct for transferring the

water from an old canal situated on the north side of the river across the river to the present Erie Canal, as a feeder for the same. He also informed me that on the 17th of March, 1867, the water was level with the floor of the planing mill referred to, elevation 357. This resulted, he stated, from the rapid melting of the snow and was not due to an ice gorge. He remarked that while the water did not rise so high at this time, there was still more water flowing in the river. At this time the present Mill Owners' dam was not constructed, but there was a dam located at this place somewhat similar in construction and about the same height, and his expression was, in regard to the water coming over this dam, that you could "just see where it was."

The elevation of the crest of this Mill Owners' dam, according to our datum, is 356. At a medium stage of the water the elevation of the river above the most westerly dam at Little Falls is 364.3, and the elevation of the water below the most easterly dam, when the river is at the same stage, is 322.5, or, in other words, the total fall of the river at this point is 41.8 feet.

In regard to Mr. Ransom's statement that the high water of 1867 was not due to an ice gorge, upon questioning him further in regard to this matter, he stated that there was probably considerable obstruction to the flow of water in consequence of the aqueduct above referred to and of the débris, etc., coming down the river and gorging at the above aqueduct and bridge above the same. If this had not been the case, it seems to me to be difficult to account for the height of this water at the place he states in the mill. I made an effort to obtain information as to a high-water mark above the upper dam for the flood of 1865 and 1867, but was unable to obtain any very definite information. I was told by a gateman of the New York Central Railroad, who was formerly a track foreman on that road, and who has been in the employ of the same for a number of years, that the flood of 1867 was probably about 2 feet deep on the New York Central tracks about a mile above Little Falls, and he told me that a large cake of ice struck a rail of this track at this point and moved it about a foot out of line. He also informed me, as well as other residents of the locality, that the ordinary spring freshet reached a certain place on the ground, which was pointed out to me, the elevation of which would, according to our datum, be about 369.2. Mr. Ransom pointed out to me at the mill where he is employed a mark which was about the usual height of the spring freshet, the elevation of which, according to our datum, would be about 350.2.

In regard to the height of the water at the Suspension Bridge below Little Falls, I made inquiry from the residents there and found from their statements that the highest water known at that point was either in 1865 or 1867. My informant was not sure which year, nor could he state definitely whether this freshet was entirely due to an ice

gorge or not, but he did state there was ice in the river and that he thought there was an ice jam about a mile below the Suspension Bridge. The elevation of this high water at this point, and indicated by him by a mark on the window frame of the hotel near the bridge, was, according to our datum, 337.2. In regard to the ordinary spring freshet, he remarked that it was about the same height each year, and pointed out a mark on a telegraph pole opposite the west end of the hotel, the elevation of which, according to our datum, is about 330.2. According to this statement, the ordinary spring freshet would reach about the top of the banks of the river above the Suspension Bridge on the north side, and be about 4 feet below the towpath of the canal on the south side.

At Jacksonburg, high water in the river overflows the flats on the north side of the river to the New York Central Railroad bank; elevation of flats, about 371.

At Herkimer, Mr. Fulmar, overseer of the dam in the West Canada Creek, about 1½ miles above Herkimer, stated that in times of lowest water in this creek no water flows over the crest of the dam, and the flow in the canal is only about two-thirds the normal flow. He stated the water was lower in the summer of 1898 than he had ever seen it. In his experience the water was also the highest he had seen it, at the time of a spring freshet in 1898, when it was over the docking on west side of dam; elevation of this docking, 429. He stated he had seen the water and ice 4 feet over the Mohawk and Malone Railroad at this dam; elevation of railroad, 427; crest of dam here, elevation 419.3.

High water in the Mohawk at Herkimer is said to have reached elevation 384, due doubtless to ice in the river.

*Canal location and conditions governing the same.*—The limits within which a canal location for either a 30 or 21 foot depth of canal prism is practical along this route are, generally speaking, the immediate bed or bottom lands of the Mohawk River.

From Herkimer to about 3 miles above Schenectady, a distance of some 60 miles, the valley has an average width of little, if any, in excess of one-half mile.

The four-track New York Central Railroad skirts along the foot of the hills on the north side of the valley, and the Erie Canal and West Shore railroads follow along the south side, the Mohawk River winding along the bottom land between, first close to the one side and then by a sudden bend to the other. Along this 60 miles are located on the banks of the river the towns or cities of Herkimer, Little Falls, St. Johnsville, Fort Plain, Canajoharie, Palatine Bridge, Fonda, Fultonville, Fort Hunter, and Amsterdam.

The located line along this 60 miles follows generally about the center of the valley, utilizing the present channel of the Mohawk as far as practical and cutting through and across the bottom lands or islands

where deemed advisable for various existing conditions and future maintenance and operation so to do. At Little Falls, for a distance of about 2 miles, the valley contracts to a narrow gorge through which the river flows, descending by a series of dams and falls a height of about 42 feet.

A short distance back from the river bank on each side, the ground rises by either steep slopes or precipitous rocky cliffs to a height of several hundred feet above the river. At this place the canal location leaves the river at about the upper or New York State dam and follows practically the location of the Erie Canal, entering the river again just below the foot of Moss Island and opposite Lock No. 36 of Erie Canal.

From about 3 miles above Schenectady to the village of Mohawk, about 1 mile below, the valley widens out, and within an area of about 2 miles above Schenectady the river separates into several branches, forming three large islands, and again converges into one channel at the bridge over the river to the village of Scotia. Within this area of bottom land is located, on the south side of the river, the main section of the city of Schenectady.

The canal location leaves the main channel at the upper end of this valley and curves through the bottom land, islands, and side channels of the river; enters the main channel again at the Scotia bridge, and follows the same closely past Mohawk to the village of Rexford Flats, about 3 miles below Schenectady.

From Rexford Flats to Vischer Ferry, a distance of about 5 miles, the general direction of the river is straight after passing the sharp bend just opposite Rexford Flats and its bed for this distance is confined for the most part between almost perpendicular rock cliffs.

The canal location cuts across the rocky point of land to the south of the river at Rexford Flats, then follows the present channel of the river to about 1½ miles above Vischer Ferry, whence it follows along the south bank and close to the Troy and Schenectady branch of the New York Central Railroad, cutting across the point of land to the south of the river opposite Vischer Ferry, and crossing the river to the north side just below the ferry.

From Vischer Ferry to the highway bridge over the river at Dunsbach Ferry, a distance of about 5 miles, the valley widens out, attaining a width of some 2 miles opposite Niskayuna, which is about 1 mile below and on the opposite side of the river from Vischer Ferry.

The canal location leaves the river after crossing the same below Vischer Ferry and cuts through the bottom land on the north side between the Erie Canal and the Mohawk, crossing the river again at Forts Ferry and across the point of land on the south side, again crossing the river about 1 mile above Dunsbach Ferry and through the rocky point of land opposite to and to the north of the West Troy Company's dam, entering the river again at Dunsbach Ferry.

From Dunsbach Ferry to the State dam opposite Cohoes, a distance of about 5 miles, the canal location follows the Mohawk to about 1 mile above Crescent. There it cuts across the sharp bend in the river about one-half mile to the south of the same and crosses the river about 1½ miles below Crescent, cutting through the small bend on the north side and entering the river again at the north end of the Cohoes Company's dam and passing down the same until the flight of locks are entered along the top of the bluff opposite and to the north of Cohoes Falls, passing out into the river again just above the State dam at Cohoes.

From the State dam at Cohoes to the entrance into the Hudson River two routes were considered, one being almost due south down the south branch of the Mohawk and entering the Hudson just above the Congress street bridge; the second across the north end of Simmons Island and through about the center of Van Schaicks Island, entering the Hudson about one-fourth mile below Twelfth street bridge at Lansingburg. The second of these two routes was adopted for the comparative estimate between this route and route down Normans Kill.

The principal condition influencing the selection of the line across Van Schaicks Island is one of operation rather than first cost of construction, in view of the fact that it would undoubtedly be a serious obstacle to successful navigation in crossing the Mohawk from the Waterford to the Cohoes side or the reverse by vessels in times of high water, necessitating as it would the partial damming of the river and the full force of flood water against the broadside of a vessel.

While the above condition will partially exist for the location across Simmons Island, the difficulties will be lessened on this route to a very appreciable extent.

The conditions governing a canal location along this Oswego route proper are controlled by a due regard to the elevation of the rock surface, where within the limits of necessary excavation; the practicable height of this rock surface where the construction of locks, dams, and other structures is contemplated; the influences upon construction and operation of the water courses, large or small, entering the valley, and the currents resulting therefrom or from the river itself in times of high water; and a canal alignment utilizing as far as practicable the present channel of the Mohawk, coupled with a due regard to the elimination of all curvature when practicable and a reduction of its degree of sharpness to within the limits of practicable navigation.

The above considerations, dependent as they are upon the physical features of the route, must also in a measure be subservient to, and due consideration given to, the present grade and location of the railroads now existing and in active operation along this route; the large expense incident to a change in them due to any unusual or unprecedented raising of the low-water level or flood discharges of the Mohawk

River and the consequent damages, due to this raising of the waters, to the lands adjacent thereto, the improvements thereon, the manufacturing enterprises and vested interests dependent upon the present existing conditions; the injury, if any, to the present plans for the disposal of sewage in the several towns and cities along the route, and the adapting of the same to the new conditions consequent upon a canal construction.

In the proper consideration of this large undertaking, each and every one of the above conditions must be given its due consideration and the merits of each interest involved that is sacrificed for the good or benefit of another or for the whole must be carefully weighed and the final location decided upon, not only after a due regard to each with reference to the first expense incurred in the carrying out of the plans, but also to the future maintenance and operation on a safe, economical, and business basis of the completed work.

*Conditions considered in comparison of 30 and 21 feet depth of channels.*—A line of investigation was taken up by the United States Board of Engineers on Deep Waterways, and approximate comparative estimates authorized, based upon the following propositions:

First. The construction of a 30-foot depth of channel of standard cross section, independent of the Mohawk River, except where the same is canalized, with same elevation of water surface in the canal and river and rectifying of the channel of said river, where necessary, to carry all flood discharges of the same and of all water courses entering it.

Second. A 30-foot depth of channel of such increased width to carry all flood discharges in the valley, with a velocity of flow not exceeding 4 feet per second.

Third. A 21-foot depth of channel of standard cross section, under the same conditions as the first proposition.

Fourth. A 21-foot depth of channel of standard cross section not designed to carry flood waters, and wholly independent of the Mohawk River except where crossing the same, and with an elevation of water surface not necessarily conforming to that of the river.

Fifth. A 21-foot depth of channel of such enlarged width, but fixed depth, to carry all flood discharges in the valley, utilizing the canalized river where practicable.

In the consideration of each of the above five propositions, the existence of the present Erie Canal was not taken into consideration, it being recognized that, prior to the construction of a ship canal along this route, an understanding would have to be arrived at and an agreement entered into between the General Government and the State of New York as to the disposition of this waterway.

*First proposition.*—The width of the canal prism for 30-foot depth at the water line is 343 feet in earth section and 256 feet in rock section. The investigation of the first proposition developed the fact

that to construct a canal under these conditions along a location within the limits of practical and economical construction would involve the contraction of the present channel and valley of the Mohawk to such an extent by reason of the necessary width for a canal and the space required for the spoiling of excavated material that no room would be left for discharging the flood waters of the valley. It would be wholly impracticable to attempt to deposit this excavated material outside of the limits of the river valley.

The heavy expense incident to the rectification of the river and the safe protection of the banks of the canal from the effects of floods, together with the heavy costs for damages to the manufacturing enterprises, railroads, etc., along the line, resulting from unusual or unprecedented raising of the waters, would all combine to render this proposition neither practicable nor economical in itself or in comparison with others.

*Second proposition.*—The apparent impracticability of the first proposition led to the investigation of the second and of its adoption for the 30-foot depth of channel as best conforming to the existing conditions and fulfilling the requirements of a waterway of this magnitude. A compiling and careful consideration of all data existing and available at the time this work was begun, combined with all information obtained during the progress of these surveys, as to the flood heights and discharges along the Mohawk Valley and the water courses tributary thereto, led to the adoption by the United States Board of Engineers on Deep Waterways of the sectional areas of canal prisms for different sections of the work, as tabulated further on in this report, starting with the standard bottom width for earth sections of 203 feet and for rock sections of 250 feet, and attaining a maximum at Schenectady, where the bottom widths for earth and rock sections are respectively 460 and 527 feet.

*Third proposition.*—An approximate estimate based on the third proposition, compared with the second, developed the advantage of each, as far as first cost of construction is concerned, the amount depending upon the cost of rock excavation. The necessary rectification of the Mohawk River in connection with the third plan is in itself a large item of expense.

Considering this from about 3¼ miles below Little Falls to the entrance of Schoharie Creek, a distance of about 31 miles, we find the width of the present channel of the river at high-water stages varies from about 325 feet at the upper end to 500 feet at the lower end. The sectional area of the river necessary to carry the flood discharges along this distance with a velocity not exceeding 4 feet per second requires a surface width of from 350 to 500 feet and a bottom width of from 229 to 382 feet, according to the estimated flood heights at different points, the depth of section ranging from 29 to 34 feet, with an average of about 30 feet. From the above it will be seen that in

the rectification of this river, following its present course, we have practically constructed a channel equal in depth and exceeding in sectional area that required for a 30-foot canal prism, but, of course, with an alignment impracticable for navigation purposes. It is self-evident, from an inspection of the maps, that it is more economical construction for the purposes of this rectification to utilize the full width of the river and increase its depth rather than materially increase the width beyond the limits of the present banks and diminish the depth.

An estimate based upon the unit price of 1 cubic yard of rock excavation being equal in cost to 4 cubic yards of earth, showed this section of about 31 miles would cost, for excavation alone, some $400,000 more for the third than for the second proposition, but, as the adoption of the former would involve the construction of some 8 miles of retaining wall with an average height of about 16 feet and a total cost of some $600,000, the total cost of the third proposition would, including this retaining wall, exceed the second by at least $1,000,000 for this distance of 31 miles.

For the 30-foot channel under the second proposition this expensive retaining wall would be replaced by slope wall. If all the rock in each estimate is taken at a unit price of 12 instead of 4 times that of earth on the basis of being excavated under water, as the case would probably be, then the cost of construction will be in favor of the third proposition by some $1,500,000. For the distance of about 10 miles to Herkimer, above the 31 miles estimated upon, the two propositions would, perhaps, not differ materially in cost, and for the distance from Schoharie Creek to Rotterdam Junction, where the adopted location leaves the river and enters the Normans Kill route, a distance of about 16 miles, the advantage in cost would probably be in favor of the second proposition. Even with the assumption, which is not believed to be true, that a careful comparative estimate of the two plans, including cost of structures and rights of way, from Herkimer to Rotterdam Junction, a distance of some 59 miles, would show that the third proposition is cheaper than the second by as much as $3,000,000 to $5,000,000. Even this amount in the first cost of a work of this magnitude and importance would hardly justify the construction of a 21-foot channel with a rectified river in preference to one of 30 feet depth.

*Fourth proposition.*—The fourth proposition involved the laying down on the maps of a location purely with reference to a 21-foot canal of standard cross section; that is, a bottom width of 215 feet for earth sections and 240 feet for rock sections, with a width at low-water line of 319 and 244 feet, respectively, the idea being not to improve or rectify the present channel of the Mohawk River or attempt to control its flood discharges except where necessary solely for the construction of the 21-foot navigable channel. This location, which was

considered impracticable and is not shown on the maps, follows the same location as the 30-foot canal from Herkimer to about 1½ miles east, then diverges from the same and follows along the bottom land between the river and the Erie Canal, entering the 30-foot canal location opposite the upper dam at Little Falls, and following this location to about 3 miles below. Here it diverges and crosses a bend in the river just above the Rocky Rift Dam, and also crosses the Erie Canal above and below Indian Castle. It then continues between the river and Erie Canal to about 2½ miles below St. Johnsville, where the location is close along the West Shore Railroad. The location would pass through about the center of that portion of Fort Plain between the railroad and Erie Canal.

From Fort Plain to Canajoharie it passes along between the Erie Canal and river, cutting out a small section of the Erie Canal at Canajoharie, and continuing east close along the north side of said canal to Sprakers and entering the canalized river for the 30-foot canal where the valley contracts at "The Noses," about 1½ miles above Yatesville. From this point it follows the 30-foot location for about 1 mile, then crosses to the north side of the river and enters separate canal about one-half mile below Yatesville, and follows close along the New York Central Railroad until it enters 30-foot channel of canalized river just above Schoharie Creek and continues east in the same.

The above location from Herkimer to the head of the locks at Little Falls would have a low-water surface in the canal of 365 and a bottom elevation of 344 feet. The water in the canal and river would be the same elevation for this distance. The lock of 11-foot lift and the dam with a weir length of 1,000 feet at Jacksonburg would not be needed. This plan would require, however, the diversion of the river to the north just below Jacksonburg for a distance of about 4,300 feet and also above Little Falls for a distance of about 2,700 feet.

No estimate was made for this portion of the 21-foot channel, as it would unquestionably be cheaper than the 30-foot channel. The sectional area of the 30-foot channel for this distance, the standard bottom width being retained, would have a depth of about 7 feet in excess of that necessary to provide for the flood discharges, but, on account of the elevation of the rock surface between Herkimer and Little Falls, it was found to be more economical construction to retain the standard depth of 21 feet and increase the bottom width about 50 feet to carry the flood waters in the 21-foot channel as far east as Little Falls.

The excavation for the double-tandem locks at Little Falls, being of less width and length, would be cheaper for the 21-foot than the 30-foot canal, as would also the section from the foot of the locks to about 3¼ miles below Little Falls, where the 21-foot canal separates

from the 30-foot. From this point to Schoharie Creek, a distance of about 31 miles, a comparative estimate was made between the fourth proposition and the adopted 30-foot channel, second proposition. This estimate embraced the necessary double-face and retaining walls, protection of slopes on the river side, estimates for puddling, and the necessary diversion of the channel of the Mohawk River, all of which are not required for the 30-foot canal. No land damages or structures were included.

The adoption of this line would involve some 6 miles of river diversion at different points along the line, the cutting out of the Erie Canal for about 2¼ miles just below St. Johnsville and also for about one-half mile at Canajoharie, also a crossing of the West Shore Railroad, unless the location was shifted, about 1 mile above and also about one-half mile below Fort Plain. Two dams would have to be constructed to impound the waters of the Mohawk, one near the present Rocky Rift dam, the crest of the masonry of which is now 319 feet elevation, with a weir length of about 350 feet and a crest elevation of 322 feet, the other (Station 6510) about three-fourths of a mile below Yatesville, with a weir length of 500 or 600 feet and a crest elevation of 285 feet. Just above this last dam the canal crosses from the south to the north side of the river. Five locks would be required; one a guard lock to regulate the low water in the canal just below the Rocky Rift dam, the flood height on this dam probably at times attaining an elevation of about 327 feet; a lock with a lift of 22 feet near Mindenville; one with a lift of 15 feet (near Station 6050) about 1¼ miles above Canajoharie; a guard lock (about Station 6510) about three-fourths of a mile below Yatesville to regulate low water in the canal, and one with a lift of 15 feet just above Schoharie Creek. The low-water level below this last lock, where the 21-foot canal enters the 30-foot canal, would be elevation 270. Castle Creek enters canal at Station 5394, requiring spillway. Otsquaga Creek enters the canal at Station 5950, and would require a spillway; also Canajoharie Creek at 5920, requiring spillway; Cayadutta Creek enters at Station 6710, requiring spillway.

The dams for the 30-foot channel at Mindenville 900 feet long, at Palatine Bridge 1,000 feet long, and at Fultonville 1,000 feet long, would not be required.

About 14 of the 31 miles of the above 21-foot channel would have a low-water surface ranging from 4 to 17 feet, and an average of 10 feet above low water in the river. The sides and bottom of the canal for the greater part of this distance being in sand or gravel, will require puddling, estimate for which is included.

The item of excavation alone, based upon earth at a unit price of 15 cents per cubic yard and rock at 60 cents per cubic yard, shows a difference between the 21-foot and 30-foot channels, propositions four and two, respectively, of some $3,980,000 in favor of the 21-foot channel for the 31 miles from about 3¼ miles below Little Falls to Schoharie

Creek. The estimate for this distance for double face walls between the canal and the river, retaining walls, slope walls, embankments, and puddling (all being needed for the 21-foot channel but not for the 30-foot channel) shows a total of some $4,529,000. This last item cancels the above amount in favor of the 21-foot channel, and shows a balance of $549,000, the difference between the two estimates, in favor of the 30-foot channel.

The above comparative estimate does not include the cost of two dams for the 21-foot channel, with a total crest length of about 900 feet, and 2 guard locks and 3 other locks, with a total lift of 52 feet. It also does not include 3 dams for the 30-foot channel, with a total crest length of 2,900 feet and 3 locks, with a total lift of 52 feet. These items of first cost, if added, would probably still leave a small balance in favor of the 30-foot channel, as far as first cost of construction is concerned, and an unquestionably large advantage as a navigable waterway, commensurate with an enterprise of this magnitude and importance.

*Fifth proposition.*—Preliminary estimates showed this proposition was probably cheaper than the second, from Herkimer as far east as the "Little Nose" (Station 6390), about 6½ miles above Fultonville.

Final estimates proved this.

There is less earth excavation by some 2,700,000 cubic yards, and less rock excavation by some 5,700,000 cubic yards, and the total cost is less by some $6,000,000 for the 21-foot than 30-foot channel for this distance of about 30 miles. Of course the saving in cost of the 21-foot channel over the 30-foot will be greater proportionally for the line west of Herkimer and from where the location leaves the Mohawk and follows the Normans Kill route.

From the "Little Nose" eastward to Rotterdam, where the Normans Kill line really begins, a distance of about 26 miles, the 21-foot channel would have to be enlarged for width and depth to such an extent to carry the flood discharges that it would practically coincide with the 30-foot channel.

### Niskayuna-Albany Route, via Shakers.

This route leaves the Oswego route proper just above Niskayuna, and extends in a south and southeast direction across country, passing just to the east of Shakers Village and West Albany, and entering the Hudson River opposite Bath, about 1 mile above Albany, N.Y.

A preliminary survey was made of this line on December 16, 17, and 18, 1897, from the Hudson River and toward Niskayuna, it being one of the three routes examined with a view to a cross-country cut-off line from the Mohawk to the Hudson, more direct and probably cheaper than the circuitous route via the Mohawk River.

This line was surveyed by stadia, the needle being used and alternate stations being occupied.

Later, this line apparently developing possibilities more favorable than the line previously run in a similar manner via Town House Corners, a more detailed survey was begun of the route in December, 1898, with a view to its development, the borings up to that time indicating favorable conditions.

The notes of the preliminary survey were worked up and an approximate canal location projected and profile made with a proposed water surface for the canal of elevation about 195 above datum from the Mohawk to within about 2 miles of the Hudson, where a flight of locks descending to the Hudson would begin. This line, about 10 miles in length, would involve excavation for its entire length, the maximum depth of cut on the flat summit being about 155 feet, and an average cutting of about 100 feet for some 6 miles.

It would have saved, in actual distance between terminal points, about 8 miles. Borings were begun on this line the latter part of November, 1898, and continued until latter part of January, 1899. These borings developed rock for lock sites within practicable depth at the Albany end.

Rock was also encountered in the borings as far as about 4 miles northwest from the Hudson at depths ranging from 40 to 70 feet below the surface, when it dipped down and no rock was found between this point and where the borings were stopped, about 1 mile north of Shakers Village, at depths ranging from 115 to 190 feet below the surface.

The material overlying the rock at the Albany end, and for about 4 miles going northwest, was principally sand and sand and gravel mixed, with some blue clay, which increased going northwestward. The material encountered where no rock was found, through the flat summit at Shakers and to the southeast and northwest of there, was fine sand and quicksand, with strata of blue clay in some of the borings. Strong flowing streams of water were encountered in several of the borings on this summit at depths of over 100 feet below the surface; this water when struck, in two instances, rising to the surface, and freely flowing from the borings after the casing was drawn.

Through this summit cut quicksand over 100 feet in depth was encountered, and it was this condition that caused the abandonment of this line and the stopping of all detailed surveys and maps of the same.

### Niskayuna-Albany Route, via Town House Corners.

This route leaves the Oswego route proper just above Niskayuna and extends in a generally southeast direction across country, passing through Watervliet Center and about three-fourths of a mile to the south of Town House Corners, thence southeast down a small stream, crossing the Delaware and Hudson Railroad and entering the Hudson River near the foot of Hillhouse Island and about 3 miles above Albany, N. Y.

A preliminary stadia survey, similar to that made of the line via Shakers, was made of this line on November 24 and 25, 1897. A map of the same was made and a canal location projected thereon and profile of the same made. Borings were begun on this line the latter part of January, 1899, and continued until the middle of February, 1899.

A proposed water surface of about elevation 192 above datum was considered. This water surface extended from the Mohawk to within about 3 miles of the Hudson, where the descent to the river by locks began

The total length of this line was about 9 miles, and it would have saved in distance between terminal points about 6½ miles.

It would involve excavation for the entire length of 9 miles, the average depth of cutting for about 5½ miles being about 100 feet. The summit cut was about 140 feet. About 3 miles of the summit cut would have been rock excavation, the surface of the rock being from 20 to 40 feet below the surface, as indicated by borings there.

The rock dipped down rapidly to the northwest from the summit cut at the highway crossing leading to Town House Corners, and at a distance of 2 miles westward of above point the borings indicated no rock at elevation 160 above datum, which was about 130 feet below the surface of the ground there.

From this point to near Watervliet Center, a distance of about 1 mile, quicksand was struck at about elevation 240 above datum, and continued to elevation 150, which was as far as the borings were carried. The encountering of this quicksand caused the abandonment of this line also.

### Schenectady-Cedar Hill Route.

This route, as first considered, was intended to leave the Oswego route proper about 3 miles above Schenectady, thence follow a generally south direction across country for about 6 miles, passing through the summit at South Schenectady and about 1¼ miles east of Dunnsville, where the head of the valley of Normans Kill is entered, thence down the valley of this stream to within about 2 miles northwest of Slingerlands, there leaving the Normans Kill and passing through the western outskirts of the village of Slingerlands, and crossing the Albany branch of the West Shore Railroad about 1 mile to the south of Wemple Station, and entering the Hudson River just below Cedar Hill Landing.

A preliminary stadia survey of this line was made during the last week in October and the first part of November, 1898. A map and profile were drawn with a view to a preliminary study of the line, and preliminary borings begun about the middle of February, 1899, on the summit at South Schenectady.

The first intention was to impound the waters of the Mohawk by a dam about 2 miles above Schenectady to elevation 225, above datum,

and carry this level to about 2½ miles southeast of French Mills, where a dam and lock with a lift of about 20 feet was proposed; from this point to carry a water level of 205 through the summit at Slingerlands by a dam of about 100 feet above the surface, and with a crest length of about 1,600 feet, across the Normans Kill about 2 miles northwest of Slingerlands, where the proposed location left the Normans Kill.

This water surface of elevation 205 was to be carried to about 3 miles southeast of Slingerlands, where two locks, with a total lift of 40 feet, were proposed. From this point a water surface of elevation 165 was to be carried to within about three-fourths of a mile of the West Shore Railroad crossing, where it was proposed to begin to lock down by a flight of locks to the Hudson.

Rock was found within practicable depths for this last flight of locks and also for the two locks proposed about 3 miles southeast of Slingerlands, although the length of the rock surface here was of barely sufficient length for two locks in tandem, and it was the only rock developed by the borings on this line from the last flight of locks to the lock about 2½ miles southeast of French Mills.

No rock was found for the high dam, about 100 feet above the surface, at the point of divergence from Normans Kill, and it was this fact, together with the long cut through the Slingerlands summit of some 3½ miles with an average depth of 40 feet through blue clay, and the large area flooded by the high dam, that led to the abandonment of this line and the examination of the route continuing down Normans Kill to the Hudson and its final adoption for the canal location.

### Schenectady-Normans Kill Route.

This route, as first authorized for consideration by the United States Board of Engineers on Deep Waterways, was intended to leave the Mohawk at the same point as the Schenectady-Cedar Mill line, but it was later deemed the best and cheapest construction to leave the Oswego Route proper by separate canal at Rotterdam Junction and pass through the summit at South Schenectady with a water surface of 240 instead of 225. With this exception the route is the same as described for the Schenectady-Cedar Hill line to within about 2 miles of Slingerlands, where, instead of leaving the Normans Kill via Slingerlands to the Hudson, the location as adopted follows down the valley of this stream, with the exception of several points of land cut through to its entrance into the Hudson River about 2½ miles below Albany.

*Field work.*—Preliminary borings as taken during February, March, and April, 1899, along this line, indicating favorable conditions, field work was resumed in the spring of 1899, and detailed surveys of this route begun.

A transit and level party combined began work at the Mohawk end of the route on April 17, 1899, and a stadia party on April 19, follow-

ing the transit party. These surveys involved not only the mapping of the line of location as shown on the preliminary map made, but also in a general way a large area probably subject to overflow, when the line was later to be considered on the detail maps when drawn. A few days were also spent in obtaining some additional data found necessary on the east side of the Mohawk opposite Cohoes Falls, and on Van Schaicks and Green islands. All the surveys were completed on June 1, 1899.

*Office work.*—The reduction of the field notes of this survey were made between June 1 and 10, at Slingerlands, N. Y., where the office of the assistant engineer was located, and the force then disbanded. Four assistants were transferred to the Detroit office to aid the force there in the plotting and drawing of the maps of this route and the computing of the estimates of quantities then in progress.

The assistant engineer, as instructed by the Board, remained in the field to direct and superintend the detail borings then in progress on this line, and which were completed the middle of July, 1899, and also to direct certain additional borings at proposed dam and lock site at Fultonville, Amsterdam, Cranesville, Rotterdam Junction, and for the dam for the Normans Kill route above Schenectady. These were finished about August 1, and the boring parties disbanded and the assistant engineer returned to Detroit.

### ARTIFICIAL FEATURES.

*Railroads.*—The West Shore Railroad, which follows down the Mohawk Valley and leaves the same going south about 3 miles above Schenectady, crosses the Delaware and Hudson Railroad at right angles at South Schenectady. The canal location for this route crosses both of these railroads in the summit cut here for the canal just to the west of where the roads cross.

It also again crosses the West Shore at the cut through the hill at French Mills, where the West Shore branch to the New York Central Railroad begins. The next crossing is the Susquehanna division of the Delaware and Hudson, where this road now crosses the Normans Kill, about 1 mile above where this stream enters the Hudson River.

The canal location as adopted will involve a change in location of this railroad here, which is estimated for. The fifth and last railroad crossing will be just before entering the Hudson, where the line crosses the Albany branch of the West Shore Railroad.

*Dams.*—There are five dams across the Normans Kill along this route. The first of these is about 800 feet above where the West Shore Railroad crosses this stream at French Mills. It is about 11 feet high, with a crest length of about 210 feet; elevation of crest, 238.5. The bed of the stream here is rock. It serves to supply power by mill-race way some 1,200 feet in length to a gristmill located there. The second dam, known as the Henkle dam, is about 500 feet above

the highway bridge over Normans Kill at Normansville. It is a log dam about 150 feet in length and with a crest elevation of 97.7.

It serves to form slack water in the stream, from which ice is cut to supply the brewery ice houses located there. The third dam, known as the Harden dam, is about 400 feet below the bridge at Normansville. It is a log dam about 210 feet in length, with a crest elevation of 87.6. It serves to supply power by a wooden penstock to a small one-story paper mill, about 200 feet below the dam.

The fourth dam is about 1,600 feet above the highway bridge crossing this stream at Kenwood. It is a log dam, about 9 feet high and with a crest length of about 190 feet; elevation of crest, 67.7. Power is supplied from this dam by means of a turbine wheel located there and transmitted by wire cable, suspended on pulleys, to the gristmill located at the south end of the bridge at Kenwood.

The fifth and last dam across this stream is about 100 feet above Kenwood Bridge. It is a crib dam, about 16 feet high, with a crest length of about 160; elevation of crest, 24.5. It formerly supplied power through turbine wheels located here to a cotton mill at the north end of the dam. This mill was recently destroyed by fire and has not been rebuilt.

*Highway crossings.*—The present line as located crosses 24 highways from the Mohawk to the Hudson. This number could easily be reduced without serious inconvenience to travel to 13 by the construction of short lengths of new road.

PHYSICAL CHARACTERISTICS.

*Material—From Rotterdam Junction (station 7754) to station 8033.*—The borings indicate no rock for this distance, except between stations 7905 and 7941, a distance of 3,600 feet. For this distance, the lower end of which is at Lock No. 24 of the Erie Canal, the borings indicate soft shale rock at about elevation 190 above datum along the south bank of the river.

This rock outcrops along this distance in the bed of the Erie Canal, elevation about 239, also along the steep hillside to the south of the Erie Canal above Lock No. 24, but dips down below the proposed grade of the canal to the south of Lock No. 24, and does not appear again until it outcrops in the bed of the small stream near station 8033, in the mouth of the ravine heading toward South Schenectady. The material for this distance is for the most part sand and sand and gravel mixed with strata of blue clay or blue clay and sand mixed.

The point of land cut through to the south of the river, where the line crosses the Fitchburg Railroad, is mostly blue clay underlying a depth of about 15 feet of soil. The point of land cut through to the north of the river, just below the Fitchburg Bridge, is gravel and cobblestones underlaid with blue clay and overlaid with about 20 feet of soil.

To the south of Lock No. 24, until the rock outcrop is encountered at about station 8033, the material is for the most part sand, with small amounts of gravel and blue clay.

*From station 8033, about 1 mile north of South Schenectady, to station 8417, about 400 feet beyond the West Shore Railroad crossing at French Mills.*—The proposed elevation of the bottom of the canal for this distance is 210 feet above datum.

The elevation of the summit at South Schenectady is 350. For the above distance of 7¼ miles from stations 8033 to 8417 the canal is entirely in excavation. Slate rock bedded in thin horizontal layers outcrops at the beginning of this section in the bed of the small stream up which the location passes and also along its banks.

The borings indicate rock in the summit cut at South Schenectady at a depth below the surface of about 25 feet, sloping down rapidly to the north, where it outcrops in the bed of the small stream, as above stated.

It also descends rapidly to the south and dips down below the grade of the canal about three-fourths of a mile to the south of the summit. The material overlying this rock is, on the summit, black and yellow sand, this being mixed with cobblestones as the surface of the rock is approached.

Southward from the summit to where the rock disappears the borings indicate a mixture of blue clay and gravel, which was very difficult to penetrate, or else fine black sand overlying the rock, and, above this, sand or sand and gravel mixed to the surface.

In one boring at the south end of the rock surface a belt of quicksand 40 feet in depth was encountered, but the elevation of the bottom of this was 75 feet above the bed of the canal, the cut at this point being about 130 feet. The borings indicate no rock from about three-fourths of a mile south of the summit for a distance of about 3 miles going south (stations 8123 to 8263). The material as indicated for this distance is fine black and yellow sand, in places mixed with small gravel, with thin strata of sand and clay or sand and shale mixed. The average cutting for this distance of 3 miles is about 85 feet.

From station 8263, about 3¾ miles south of the summit, to French Mills, rock was encountered at from elevation 210, the bottom of the canal here, to elevation 240, except in the bottom land just to the north and south of the high point of land cut through at French Mills, where the elevation of the rock surface ranged from 182 to 195.

The material overlying the rock and extending to the surface for this distance is coarse, dark sand and small gravel mixed with stiff, blue clay and some cobblestones, and penetration through the same was difficult and tedious. This material is characteristic of this route as far east as station 8663, which is at the highway crossing leading to Voorheesville.

The combined ingredients mentioned above form a hard, compact mass, and yet quite different from the cemented gravel outcropping in places along the Mohawk Valley. This cemented gravel resisted attempts to crack it to pieces with a small hammer, and formed a mass almost equal in strength to the best concrete, whereas this material could be shattered with a sharp blow when in a thoroughly dry mass. The same material outcrops in steep banks at the sharp bend in Normans Kill, about 2½ miles southeast of French Mills. It stands at an almost perpendicular slope and resists erosion to a marked degree and shows no tendency to slide.

A boring in the point of land cut through at French Mills indicated soft blue and yellow clay to a depth of 75 feet below the surface, and beneath this about 20 feet of black sand and clay mixed.

*From French Mills (station 8417) to Highway Crossing to Voorheesville (station 8663).*—For the above distance of 4¾ miles there is little or no excavation, the bottom land of the Normans Kill being at about the same elevation as canal bottom, the principal exception being about 2½ miles southeast of French Mills, where the location is shifted to the hill to the south of the stream to obtain a rock foundation for the locks located there. Soft slate rock outcrops in the bed of Normans Kill just above and below French Mills; also, steep slate cliffs are on each side of the stream there, and extend along the west side of the stream for a distance of about 1 mile below French Mills.

This rock is bedded horizontally, and along the cliffs above referred to strata of harder rock is found from 2 to 4 feet in thickness, with soft shale above and below the same.

The borings developed rock about 2 miles below French Mills at an elevation of from 255 to 275 above datum. This rock surface was barely of sufficient length, however, for the location of one lock. About one-half mile below this place, where there is a sharp bend in the stream, slate rock outcrops in thin horizontal layers in the bed of the stream, and also in a perpendicular cliff to the south of the stream. The borings also developed rock at a depth of from 120 to 165 feet above datum in the hill to the south of the sharp bend and to the south of the stream. This is the last rock found on this route to within about 1 mile above Normansville. The character of the material from French Mills to station 8663 is for the most part the same as that found for 3 miles above French Mills, which is sand and small gravel mixed with blue clay.

*From station 8663 to about 1 mile above Normansville (station 8923).*—The borings developed no rock within this distance. The material is blue clay, almost entirely free from all grit, and is characteristic of the above-mentioned section. It is also found as far east as the Hudson River.

Evidence on the ground, and from information obtained as to conditions met with in excavating this material for the Delaware and

Hudson Railroad when built, would indicate that this blue clay has a tendency to slide, especially where springs are met with. I think, however, this condition can in a measure be avoided with an increase in slope and proper surface drains along the top of and well back from cuts. In places this clay was soft, but the borings in most cases indicate "stiff, blue clay." It molds easily in the hand; is when wet sticky, and when exposed to the sun becomes very hard, and can be shaved with a knife in a manner similar to chalk. It stood up well in most of the borings, and the drill rods could be carried down through the same without the use of casing. Along the banks of streams it presents a hard surface, and at a distance has the appearance of soft shale rock.

*From station 8923 to the Hudson River.*—Soft shale rock outcrops along the south bank of Normans Kill at the beginning of this section. On the north side of the stream, just where the location crosses, there is a perpendicular cliff of a hard, dark-colored rock, probably impregnated with iron. This character of rock probably extends through this hill to the next crossing of the stream (station 8953).

From this point down the stream to where the location crosses below Normansville soft shale outcrops on both sides of the stream and in the bed, and the indications are this will be the character of the rock encountered opposite to and just below Normansville.

From where the location enters the deep cut just below the crossing of the Delaware and Hudson Railroad to Kenwood the indications are the excavation will be, for the most part at least, through a hard rock of the nature of a limestone conglomerate similar to that which freely outcrops in steep cliffs above Kenwood, and through which the Delaware and Hudson Railroad has made a deep cut here.

This harder rock probably merges into and is stratified with shale rock, approaching Kenwood and from there to the Hudson, as shale outcrops on the banks of the stream at Kenwood, and also the hard rock on the south side of the stream here.

The material overlying the rock for this distance, and where no rock was found, is almost wholly blue clay, similar to that already described. In some places strata of yellow clay overlies the blue clay.

### WATER COURSES AND HIGH-WATER MARKS.

Normans Kill, by which this route is designated, is the principal water course encountered, and the located line, as adopted, follows down the valley of the same for about two-thirds its length.

It has several tributaries along its course.

In a report of the water commissioners to the Albany common council in 1891, as to the advisability of the utilization of this stream as a water supply for the city of Albany, it is stated the catchment area above French Mills is some 114 square miles. It is further stated that from measurements taken in February, 1891, it appears that the

flow then, during a moderate thaw, was at the rate of about 1,240 cubic feet per second. I presume this is at or near French Mills. The maximum flood height on the Harden Dam at Normansville is said to be 4 feet. This would indicate the flood discharge here is about 1,800 cubic feet per second.

The maximum flood height on the dam just above the highway crossing at Kenwood is said to be 8 feet, indicating a discharge of about 2,200 cubic feet per second. As to how reliable this information is I am unable to state.

### CANAL LOCATION ALONG THIS ROUTE AND CONDITIONS INFLUENCING ITS SELECTION.

As a result of the borings made for the proposed dam above Schenectady to impound the waters of the Mohawk for this line, it was found this dam, with a crest length of about 1,700 feet and an elevation of 225, with about 5 feet flood height on the crest, would have to be founded at its south end on a top strata of yellow sand and clay to a depth of about 40 feet, and beneath this about 19 feet of quicksand overlying blue clay and sand.

From the center of the dam about to its north end, the material was coarse sand and gravel for a depth of about 20 feet below the surface and beneath this 70 feet of quicksand.

This condition, together with the fact of the advisability of carrying as high a water surface as possible through the long summit cut of rock at South Schenectady, led to the abandonment of this dam above Schenectady, and the carrying of a water surface of elevation 240 through this summit, which is the elevation of the crest of the dam at Rotterdam Junction and the location of a guard lock there to regulate low water in the canal. The flood height as estimated on this dam will be about 7 feet. Under this plan the Normans Kill location will properly begin at Rotterdam Junction by separate canal, the river being rectified below this place until the location leaves the same, the canal being protected and separated from the rectified river by a wall. This wall would be about 11,300 feet in length, separated into three sections of 2,000, 4,500, and 4,800 feet, respectively. The first two sections will be founded on sand and gravel and a liberal estimate is made, including proper precautions for secure and safe construction for these sections.

The last section of 4,800 feet can be founded on a rock foundation with the exception of about 1,000 feet at the lower end, the surface of the rock being about 20 feet below the bed of the canal.

Estimates include puddling the bottom of the canal and the side opposite and the wall, and also revetting the same, as the low water in the rectified river will be in places from 20 to 25 feet below the surface of the canal. Additional borings necessary previous to construction may indicate a reduction in width of channel along this 4,800 feet

above referred to as being desirable in order to obtain a rock footing at a less depth for this wall. The last 1,000 feet where no rock will probably be found within practicable depth will be located without the limits of the present river channel, a secure foundation for the same being estimated for.[1]

The conditions influencing the United States Board of Engineers on Deep Waterways in the selection of this route via the Normans Kill over that by the Mohawk River were these: It is is shorter by 11.9 miles between terminal points; it avoids the sharp curvature at Rexford Flats and Crescent, and the general alignment is better; it avoids a provision for the discharge of the sewerage from Schenectady; it avoids drawbridges at Schenectady, Cohoes, and Albany for passing the New York Central Railroad; heavy land damages for property destroyed at the Hudson River end and interference with the vested water rights at Cohoes are avoided. Six railroad drawbridges will be required on the Mohawk line, one of these for four tracks and three for double tracks.

[1] After the completion of Mr. Howell's report the junction of the Normans Kill cut-off with the Mohawk River section was considered by the Board and the following plan adopted:

The Rotterdam Junction dam and guard lock are moved downstream, so that the Fitchburg Railroad crosses the lock without altering the alignment of the railroad. This change reduces the length of the bridge without adding any obstructions to navigation. With the lock above the bridge, as originally planned, owing to the acute angle of the crossing the clear opening could not have been more than 100 feet. As the lock is a guard lock and would be needed only for a few days during the navigation season, this plan would not seriously interfere with the railway traffic. The dam is located opposite the upper end of the guard lock and is connected with the lock wall and with the high ground on the left by embankments strengthened by core walls. As the elevation of water surface in the canal and river is to be the same, the 2,000 feet of wall from station 7771 to station 7791 will not be needed.

From the lower end of the guard-lock station 7806 to station 7910 the canal location is shifted to the right sufficiently to leave a space about 400 feet wide between the canal and river. This new location is shown as an alternate line on plate 29. The rectified river channel from station 7900 to station 7960 has also been relocated. The new channel is along the foot of the hills on the left of the valley. This change leaves a space of about 600 feet between the two channels.

These changes of location were made in order that the masonry walls from 7818 to 7863 and from 7905 to 7953 might be replaced by embankments. It is proposed to build an embankment next to the canal 50 feet wide on top with side slopes of 1 on 2. The embankment is to be built 5 feet above low water in the canal, and is to be strengthened by core walls wherever necessary. The space between the levee and the river channel will be used as a spoil bank and will be filled at least as high as the top of the former from the waste from the excavation. The river face of the fill is to be protected by a slope wall.

This form of construction reduces the estimated cost of the 30-foot channel by $2,126,207, and of the 21-foot channel by $2,570,398.

Besides reducing the cost of construction, it is believed that the substitution of wide embankments for the high masonry walls on poor foundations adds greatly to the safety of the canal.

There are five railroad crossings on the Normans Kill line, two of which are double track. Two of these at South Schenectady and the one at French Mills can have fixed spans.

The raising of the Troy and Schenectady Branch of the New York Central Railroad above and below Niskayuna for the Mohawk line will probably offset the change in tracks of the Delaware and Hudson Railroad above Kenwood for the Normans Kill line. If the Erie Canal is considered in the comparison the Normans Kill line crosses the same above Schenectady at about the same water level and avoids interference with the same at the Rexford Flats and Crescent aqueducts. Nine draw spans for highway crossings are required for the Mohawk line, where not over thirteen and probably less will have to be provided for on the Normans Kill line. Two of these can be fixed spans.

The Normans Kill line is shown by comparative estimates to be about $20,000,000 cheaper than the Mohawk line, exclusive of structures in both cases.

30-FOOT ADOPTED CHANNEL.

The location for this channel, as finally adopted, and which is shown on the published maps and profiles of this route accompanying and forming a part of this report, follows in general the Mohawk Valley from Herkimer to Rotterdam Junction, where it leaves the Mohawk River and follows, via South Schenectady, the Normans Kill route to the Hudson River, entering the same, as stated, about 2½ miles below Albany, N. Y. Its total length is 81.75 miles.

The conditions influencing the size of canal prism along the line and its enlargement to provide for carrying the estimated flood discharges are questions which will be discussed by the United States Board of Engineers on Deep Waterways in their report. The width, depth, and serviceable lengths of locks for large and small chambers, with arrangement of gates and operating machinery, will also be discussed by the Board.

The estimated cost of this channel, under changes in railroads, includes the raising of the New York Central and West Shore railroads along the Mohawk Valley, wherever necessary, to an elevation of base of rail 3 feet above the estimated flood heights on all dam crests. Under land damages are included right of way for canal prism and the necessary land for spoil banks, all area overflowed or rendered useless by such overflow, all buildings destroyed, all actual injury to, destruction of, or interference with existing water rights, or present disposal of sewage of towns or cities along the line.

*Water supply.*—This question is not discussed in this report, and is left to others whose duty it was, under authority from the United States Board of Engineers on Deep Waterways, to investigate this question. I have assumed this water supply as furnished for either the 21-foot or 30-foot channel at Herkimer, N. Y., the western end of this division.

TABLE NO. 4.—*Canal prism, 30-foot channel.*

| Location. | | Earth. | | Rock. | |
|---|---|---|---|---|---|
| From— | To— | Section. | Bottom width. | Section. | Bottom width. |
| | | *Sq. feet.* | *Feet.* | *Sq. feet.* | *Feet.* |
| Herkimer (station 4789+92) | East Canada Creek (station 5479+92). | 7,890 | 203 | 7,500 | 250 |
| East Canada Creek (station 5479+92). | Mindenville (station 5559+92) | 8,520 | 224 | 8,790 | 293 |
| Mindenville (station 5559+92) | Caroga Creek (station 5819+92). | 8,520 | 224 | 8,490 | 283 |
| Caroga Creek (station 5819+92). | Palatine Bridge (station 6036+92). | 9,000 | 240 | 9,180 | 306 |
| Palatine Bridge (station 6036+92). | "Little Nose" (station 6389+92). | 9,000 | 240 | 8,640 | 288 |
| "Little Nose" (station 6389+92). | Fultonville (station 6680+92) | 10,500 | 290 | 10,620 | 354 |
| Fultonville (station 6680+92) | Schoharie Creek (station 6989+92). | 10,500 | 290 | 9,750 | 325 |
| Schoharie (station 6989+92) | Amsterdam (station 7214+92) | 13,980 | 406 | 14,400 | 480 |
| Amsterdam (station 7214+92) | Cranesville (station 7453+45) | 15,600 | 460 | 15,300 | 510 |
| Cranesville (station 7453+45) | Rotterdam Junction (station 7732+30). | 15,600 | 460 | 15,420 | 514 |
| Rotterdam Junction (station 7732+30). | Kenwood (station 9059+83) | 7,890 | 203 | 7,500 | 250 |
| Kenwood (station 9059+83) | Hudson River (station 9106+19) | Irregular-shaped basin entering the Hudson River. | | | |

NOTE.—In the above table, change of section at approach to and leaving locks and for curves, where necessary, is not noted.

TABLE NO. 5.—*Dams for 30-foot and 21-foot channels.*

| Location. | Station. | Length of crest. | Elevation of crest above datum. | Height of dam above river or stream bed. | Character of structure. | Foundation and average elevation of rock surface. | |
|---|---|---|---|---|---|---|---|
| | | *Feet.* | *Feet.* | *Feet.* | | | |
| Jacksonburg | 4935 | 1,000 | 376 | 16 | Masonry | Rock | 350 |
| Little Falls | 5120 | 650 | 365 | 5 | do | do | 355 |
| Mindenville | 5558 | 900 | 322 | 20 | do | do | 290 |
| Palatine Bridge | 6032 | 1,000 | 300 | 20 | do | do | 270 |
| Fultonville | 6676 | 1,000 | 285 | 12 | do | do | a 212 |
| Amsterdam | 7210 | 850 | 270 | 20 | do | do | 226 |
| Cranesville | 7453 | 1,000 | 255 | 20 | do | Pile foundation. | |
| Rotterdam Junction | 7753 | 1,100 | 240 | 22 | do | Do. | |
| French Mills | 8418 | 250 | 240 | 13 | do | Rock | 227 |
| | 8510 | 350 | 225 | 50 | do | do | 150 |
| | 8548 | 550 | 205 | 50 | do | do | 120 |
| Above Normansville | 8931 | 600 | 165 | 75 | do | do | 110 |
| Above Kenwood | 9027 | 400 | 103½ | 48 | do | do | 70 |

a Pile foundation.

The dam at Fultonville (station 6676) in order to obtain a rock footing, would necessitate the carrying of the foundation about 60 feet below the river bed.

The material here on the south end of the dam and south side of the river is a belt of yellow clay for 9 feet below the surface, underlaid by fine sand and sand and clay mixed for a depth of about 24 feet, and beneath this about 10 feet of blue clay, overlying gravel and bowlders down to elevation 230, at which depth no rock was struck. On the north shore of the river rock was encountered at elevation 211, the material passed through being sand and sand and clay mixed, with about 6 feet of gravel on top of the rock.

The elevation of the rock next to the New York Central Railroad is 245.

The borings for the dam at Amsterdam (station 7210) developed rock about halfway across the dam from the north end at elevation about 200. For the south half no rock was found at elevation 174.

The material is for the most part sand, gravel, and bowlders.

The borings for the dam at Cranesville (station 7453) developed rock in only one boring at elevation 170.

The material here is sand, gravel, and bowlders, with thin strata of blue clay and hardpan.

The dam at Rotterdam (station 7753) will have to be founded on sand and sand and gravel mixed down to elevation about 210, and beneath this blue clay and sand mixed for about 50 feet, at least.

TABLE NO. 6.—*Locks for 30-foot and 21-foot channels.*

| Number. | Location. | | Kind. | | Lift. | Total lift. | Length of level. | Character of foundation | |
|---|---|---|---|---|---|---|---|---|---|
| | Place. | Station at center of lock. | Single or double. | Individual or in flight. | | | | 30-foot channel. | 21-foot channel. |
| | | | | | *Feet.* | *Feet.* | *Miles.* | | |
| 11 | Jacksonburg | 4940 | Single | Individual | 11 | 11 | 4.2 | Rock | Rock. |
| 12,13 | Little Falls | 5165 | Double | Flight | 21.5 | 43 | 7.6 | do | Do. |
| 14 | Mindenville | 5563 | Single | Individual | 22 | 22 | 9 | do | Do. |
| 15 | Palatine Bridge | 6037 | do | do | 15 | 15 | 12.2 | do | Do. |
| 16 | Fultonville | 6680 | do | do | 15 | 15 | 10.1 | do | Pile. |
| 17 | Amsterdam | 7215 | do | do | 15 | 15 | 4.6 | do | Rock. |
| 18 | Cranesville | 7459 | do | do | 15 | 15 | ..... | Pile | Pile. |
| 19 | Rotterdam Junction. | 7751 | do | do | Guard lock. | | ..... | do | Do. |
| 20 | French Mills | 8406 | do | do | 15 | 15 | 17.9 | Rock | Rock. |
| 21 | Normans Kill line. | 8511 | do | do | 20 | 20 | 2 | do | Pile. |
| 22,23 | do | 8555 | Double | Flight | 20 | 40 | 0.8 | do | Rock. |
| 24,25,26 | do | 8955 | do | do | 20.5 | 61.5 | 7.5 | do | Do. |
| 27,28,29,30,31 | do | 9040 | do | do | *a* 20.7 | 103.5 | 1.4 | do | Do. |
| | Total | | | | | 376 | | | |

*a* This lift is taken at 20.7 to provide for a possible minimum low water at the lower end of lock.

COST OF LOCKS.

| No. of lock. | 30-foot channel. | 21-foot channel. | Operating machinery. |
|---|---|---|---|
| 11 | $912,926 | $560,968 | $100,000 |
| 12,13 | 3,571,594 | 2,434,589 | 175,000 |
| 14 | 1,123,687 | 684,348 | 100,000 |
| 15 | 1,010,095 | 615,861 | 100,000 |
| 16 | 1,015,283 | 721,484 | 100,000 |
| 17 | 1,062,977 | 648,475 | 100,000 |
| 18 | 1,245,321 | 765,818 | 100,000 |
| 19 | 965,777 | 629,650 | 100,000 |
| 20 | 884,446 | 577,289 | 100,000 |
| 21 | 966,258 | 728,626 | 100,000 |
| 22,23 | 3,114,687 | 2,172,165 | 175,000 |
| 24,25,26 | 4,720,697 | 3,065,295 | 225,000 |
| 27,28,29,30,31 | 7,445,609 | 4,533,769 | 350,000 |
| Total | 28,039,357 | 18,138,257 | 1,825,000 |
| Operating machinery | 1,825,000 | 1,825,000 | ..... |
| Total | 29,864,357 | 19,963,257 | ..... |

NOTE.—Lift of locks as given is for low-water level.

The elevation of the rock above the lock at Cranesville (station 7459) is about 170, and below the same about 208, as indicated by the borings.

The material is of about the same nature as for the dam here.

There is no rock for the lock at Rotterdam Junction (station 7751). The material is the same as that described for the dam here.

TABLE NO. 7.—*Bridges.*

OSWEGO-MOHAWK ROUTE, EASTERN DIVISION.

| Station. | Location. | Kind of bridge. | Number of tracks | Swing or fixed. | Number of spans. | 30-foot channel. | | 21-foot channel. | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Total length. | Estimated cost. | Total length. | Estimated cost. |
| 5135 | Little Falls | Highway | | Swing | 1 | 545 | $67,862 | 525 | $66,382 |
| 5217 | do | do | | do | 1 | 545 | 105,868 | 525 | 90,666 |
| 5650 | St. Johnsville | do | | do | 1 | 545 | 72,572 | 525 | 71,092 |
| 5948 | Fort Plain | do | | do | 1 | 545 | 92,250 | 525 | 90,770 |
| 6115 | Canojarharie | do | | do | 1 | 545 | 71,834 | 525 | 70,354 |
| 6735 | Fonda | do | | do | 1 | 545 | 108,220 | 525 | 90,344 |
| 6982 | Fort Hunter | do | | do | 1 | 545 | 113,442 | 525 | 111,962 |
| 7260 | Amsterdam | do | | do | 1 | 545 | 149,962 | 525 | 148,482 |
| 7661 | Hoffmans Ferry | Railway | 2 | do | 1 | 550 | 275,589 | 530 | 263,249 |
| 7804 | Rotterdam Junction | do | 1 | do | 1 | 463 | 87,331 | 423 | 75,512 |
| 8020 | | Highway | | do | 1 | 545 | 97,106 | 525 | 81,090 |
| 8071 | South Schenectady | Railway | 2 | Fixed | 1 | 600 | 307,342 | 580 | 287,712 |
| 8085 | do | do | 1 | do | 1 | 375 | 81,078 | 363 | 76,638 |
| 8088 | do | Highway | | do | 1 | 315 | 40,784 | 305 | 39,940 |
| 8195 | | do | | Swing | 1 | 545 | 97,106 | 525 | 81,090 |
| 8302 | | do | | do | 1 | 545 | 64,104 | 525 | 59,320 |
| 8413 | French Mills | Railway | 1 | Fixed | 1 | 260 | 39,412 | 250 | 37,057 |
| 8414 | do | Highway | | do | 1 | 260 | 23,394 | 250 | 22,711 |
| 8485 | | do | | Swing | 1 | 545 | 97,106 | 525 | 81,090 |
| 8615 | | do | | do | 1 | 545 | 97,106 | 525 | 81,090 |
| 8663 | | do | | do | 1 | 545 | 97,106 | 525 | 81,090 |
| 8813 | | do | | do | 1 | 545 | 97,106 | 525 | 81,090 |
| 8960 | Normansville | do | | do | 2 | 335 | 20,476 | 296 | 17,140 |
| 9011 | | Railway | 1 | do | 1 | 537½ | 141,938 | 517½ | 120,300 |
| 9041 | Kenwood | Highway | | do | 1 | 235 | 15,946 | 196 | 12,610 |
| 9058 | do | Railway | 1 | do | 1 | 228 | 21,773 | 197 | 17,215 |
| | Normans Kill *a* | Highway | | Fixed | 1 | 100 | 4,810 | 100 | 4,810 |
| 4275 | Kenwood *a* | Railway | 1 | do | 1 | 150 | 12,234 | 150 | 12,234 |
| | Hoffmans Ferry *a* (steam ferry). | | | | | | 20,000 | | 20,000 |
| | Total | | | | | | 2,520,807 | | 2,293,040 |

*a* Bridges not over canal.

| | Feet clear opening. |
|---|---|
| Highway bridges | 22 |
| Single-track railway bridges | 14 |
| Double-track railway bridges | 26 |

21-FOOT ADOPTED CHANNEL.

The location as adopted for this channel is the same as that described for the 30-foot channel, and its total length is the same. The same statements made for the 30-foot channel, as to the size of prism, locks, and estimated costs for change of railroads and land damages, apply also to this channel.

The alignment is the same for this channel as for the 30-foot channel.

The two channels are the same for depth and sectional area from the "Little Nose" (station 6389+92) to the head of the lock at Rotterdam Junction, which is the beginning of the Normans Kill line, for the reasons already stated in this report.

TABLE NO. 8.—*Canal prism 21-foot channel.*

| Location. | | Earth. | | Rock. | |
|---|---|---|---|---|---|
| From— | To— | Section. | Bottom width. | Section. | Bottom width. |
| | | *Sq. feet.* | *Feet.* | *Sq. feet.* | *Feet.* |
| Herkimer (station 4789+92) | West Canada Creek (station 4849+92). | 5,397 | 215 | 5,040 | 240 |
| West Canada Creek (station 4849+92). | Jacksonburg Creek (station 4938+92). | 7,014 | 292 | 7,098 | 338 |
| Jacksonburg (station 4938+92) | Little Falls Creek (station 5119+92). | 6,489 | 267 | 6,552 | 312 |
| Little Falls (station 5119+92) | Little Falls Creek (station 5161+92). | 5,397 | 215 | 5,040 | 240 |
| Little Falls (station 5161+92) | East Canada Creek (station 5479+92). | 6,489 | 267 | 6,552 | 312 |
| East Canada Creek (station 5479+92). | Mindenville (station 5561+92) | 8,043 | 341 | 8,190 | 390 |
| Mindenville (station 5561+92) | Garoga Creek (station 5819+92). | 7,623 | 321 | 7,665 | 365 |
| Garoga Creek (station 5819+92). | Palatine Bridge (station 6035+92). | 8,526 | 364 | 8,526 | 406 |
| Palatine Bridge (station 6035+92). | Little Nose (station 6389+92) | 7,791 | 329 | 7,812 | 372 |
| Little Nose (station 6389+92) | Fultonville (station 6680+92) | 10,500 | 290 | 10,620 | 354 |
| Fultonville (station 6680+92) | Schoharie Creek (station 6989+92). | 10,500 | 290 | 9,750 | 325 |
| Schoharie Creek (station 6989+92). | Amsterdam (station 7214+92) | 13,980 | 406 | 14,400 | 480 |
| Amsterdam (station 7214+92) | Cranesville (station 7453+45) | 15,600 | 460 | 15,300 | 510 |
| Cranesville (station 7453+45) | Rotterdam Junction (station 7732+30). | 15,600 | 460 | 15,420 | 514 |
| Rotterdam Junction (station 7732+30). | Kenwood (station 9052+53) | 5,397 | 215 | 5,040 | 240 |
| Kenwood (station 9052+53) | (Station 9106+19) | Irregular shaped basin entering Hudson River. | | | |

In the above table change of section at approach to and leaving locks, and for curves where necessary, is not noted.

The canal prism is the same for this channel as for the 30-foot channel from station 6389+92 to station 7732+30.

*Dams.*—Table No. 5, as given for 30-foot channel, also applies to this channel.

*Locks.*—Table No. 6 includes the locks on the 21-foot channel.

At Fultonville (station 6680) the rock for the lock for this channel is about 15 feet below the bottom of the foundation. The material is clay and fine sand, loosely mixed for about 30 feet below the surface, overlying about 10 to 20 feet of soft, blue clay, and beneath this sand, gravel, and bowlders extending to the rock surface at elevation about 222.

There is no rock for the lock at Cranesville (station 7458). The material is sand, gravel, and bowlders, with thin strata of blue clay and hardpan. The material at Rotterdam Junction (station 7751) for the lock is the same as that described for the dam there.

The borings indicate rock at about the elevation of the bottom of the foundation in the center of the lock at station 8511, but the rock is about 17 feet below the same at its west end and about 60 feet below at its east end.

The material is for the most part blue clay and gravel mixed, and is hard.

*Bridges, railroad and highway.*—The table for the above, as given for 30-foot channel, also applies to this channel.

TABLE NO. 9.—*Oswego-Mohawk route, eastern division—Estimate of construction of 30-foot channel.*

SECTION NO. 1 (STATION 4789 + 91.5 TO 4848 + 00), FROM HERKIMER TO 1¼ MILES EAST OF HERKIMER.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Excavation: | | | |
| Gravel, cubic yards | 1,211,024 | $0.18 | $217,984 |
| Sand, do | 725,897 | .18 | 130,661 |
| Earth, do | 725,896 | .18 | 130,661 |
| Right of way, farm land, acres | 189 | 100.00 | 18,900 |
| Entrance of streams, submerged weirs | | | 2,352 |
| Slope wall, square yards | 31,703 | 1.10 | 34,873 |
| Total | | | 535,431 |

SECTION NO. 2 (STATION 4848 TO STATION 5118), FROM 1¼ MILES EAST OF HERKIMER TO LITTLE FALLS.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, quartzite, wet, cubic yards | 295,951 | $2.50 | $739,878 |
| Rock, quartzite, dry, do | 854,600 | .75 | 640,950 |
| Rock, quartzite, artificially dry, do | 709,818 | 1.00 | 709,818 |
| Clay, do | 988,104 | .18 | 177,859 |
| Gravel, do | 861,281 | .18 | 155,031 |
| Sand, do | 3,504,267 | .18 | 630,768 |
| Earth, do | 1,630,330 | .18 | 293,459 |
| Diversion and levees | | | 85,000 |
| Right of way: | | | |
| Farm land, acres | 868 | 100.00 | 86,800 |
| Town land, do | 5 | 14,286.00 | 71,430 |
| Railroad changes, miles | 3.05 | | 23,851 |
| Retaining wall, cubic yards | 270,271 | 4.00 | 1,081,084 |
| Slope wall, square yards | 42,584 | 1.10 | 46,842 |
| Back fill, cubic yards | 759,282 | .25 | 189,821 |
| Timber cribs: | | | |
| Oak, feet B. M. | 103,440 | a 50.00 | 5,172 |
| Hemlock, do | 7,267,067 | a 23.00 | 167,143 |
| Pine, do | 3,060,093 | a 30.00 | 91,803 |
| Stone fill, cubic yards | 122,640 | .60 | 73,584 |
| Iron bolts, pounds | 852,013 | .03 | 25,560 |
| Lock No. 11 | | | 912,926 |
| Operating machinery | | | 100,000 |
| Dams: | | | |
| Concrete, dam and wing, cubic yards | 21,606 | 6.00 | 129,636 |
| Concrete, core wall, do | 10,000 | 4.50 | 45,000 |
| Excavation, earth, do | 53,630 | .18 | 9,653 |
| Embankment, do | 45,750 | .15 | 6,863 |
| Cofferdam | | | 12,800 |
| Total | | | 6,512,731 |

SECTION NO. 3 (STATION 5118 TO STATION 5175), LITTLE FALLS.

| | | | |
|---|---|---|---|
| Excavation, rock quartsite, dry, cubic yards | 2,324,504 | $0.75 | $1,743,378 |
| Right of way: | | | |
| Farm land, acres | 47 | 100.00 | 4,700 |
| Town land, do | 37 | 22,124.00 | 818,588 |
| Retaining wall, cubic yards | 44,811 | 4.00 | 179,244 |
| Timber crib: | | | |
| Oak, feet B. M. | 19,200 | a 50.00 | 960 |
| Hemlock, do | 1,000,000 | a 23.50 | 23,000 |
| Pine, do | 378,400 | a 30.00 | 11,352 |
| Stone fill, cubic yards | 16,380 | .60 | 9,828 |
| Iron bolts, pounds | 137,660 | .03 | 4,130 |
| Locks Nos. 12 and 13 | | | 3,571,594 |
| Operating machinery | | | 175,000 |
| Dams: | | | |
| Concrete, dam and wing walls, cubic yards | 5,150 | 6.00 | 30,900 |
| Excavation, earth, do | 6,610 | .18 | 1,190 |
| Cofferdams | | | 27,000 |
| Bridge | 1 | | 67,862 |
| Total | | | 6,668,726 |

a Per 1,000 feet.

TABLE NO. 9.—*Oswego-Mohawk route, eastern division—Estimate of construction of 30-foot channel*—Continued.

SECTION NO. 4 (STATION 5175 TO STATION 5260), FROM LITTLE FALLS TO THREE-FOURTHS OF A MILE BELOW SUSPENSION BRIDGE.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Excavation: | | | |
| Rock, hard, artificially dry.....cubic yards | 128,721 | $1.00 | $128,721 |
| Sand.....do | 2,013,232 | .18 | 362,382 |
| Diversions and levees | | | 10,000 |
| Right of way, farm land.....acres | 293 | 100.00 | 29,300 |
| Slope wall.....square yards | 51,131 | 1.10 | 56,244 |
| Back fill.....cubic yards | 37,152 | .25 | 9,288 |
| Timber crib: | | | |
| Oak.....feet B. M. | 35,040 | *a* 50.00 | 1,752 |
| Hemlock.....do | 3,476,260 | *a* 23.00 | 79,954 |
| Pine.....do | 968,820 | *a* 30.00 | 29,065 |
| Stone fill.....cubic yards | 55,840 | .60 | 33,504 |
| Iron bolts.....pounds | 392,695 | .03 | 11,781 |
| Bridge | 1 | | 105,868 |
| Total | | | 857,859 |

SECTION NO. 5 (STATION 5260 TO STATION 5651), FROM THREE-FOURTHS OF A MILE BELOW SUSPENSION BRIDGE TO ST. JOHNSVILLE.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry.....cubic yards | 1,585,022 | $0.65 | $1,030,264 |
| Rock, artificially dry.....do | 2,109,283 | .75 | 1,581,962 |
| Clay.....do | 251,776 | .18 | 45,320 |
| Gravel.....do | 1,815,080 | .18 | 326,714 |
| Sand.....do | 4,622,108 | .18 | 831,979 |
| Earth.....do | 1,519,296 | .18 | 273,473 |
| For lock at additional price: | | | |
| Earth.....do | 255,707 | .32 | 81,862 |
| Rock.....do | 185,593 | .50 | 92,797 |
| Diversion and levees | | | 200,000 |
| Right of way, farm land.....acres | 2,200 | 100.00 | 220,000 |
| Railroad changes.....miles | 4.22 | | 73,795 |
| Entrance of streams, submerged weirs | | | 2,006 |
| Retaining wall.....cubic yards | 327,737 | 4.00 | 1,310,948 |
| Slope wall.....square yards | 81,492 | 1.10 | 89,641 |
| Back fill.....cubic yards | 537,086 | .25 | 134,272 |
| Timber cribs: | | | |
| Oak.....feet B. M. | 83,040 | *a* 50.00 | 4,152 |
| Hemlock.....do | 5,970,360 | *a* 23.00 | 137,318 |
| Pine.....do | 1,763,200 | *a* 30.00 | 52,896 |
| Stone fill.....cubic yards | 109,350 | .60 | 60,210 |
| Iron bolts.....pounds | 668,886 | .03 | 20,067 |
| Lock No. 14 | | | 1,123,687 |
| Operating machinery | | | 100,000 |
| Dam: | | | |
| Concrete.....cubic yards | 35,960 | 6.00 | 215,760 |
| Excavation, earth.....do | 68,944 | .50 | 34,472 |
| Cofferdam | | | 20,000 |
| Bridge | 1 | | 72,572 |
| Total | | | 8,136,131 |

SECTION NO. 6 (STATION 5651 TO STATION 6103), FROM ST. JOHNSVILLE TO CANAJOHARIE.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, wet.....cubic yards | 591,155 | $2.00 | $1,182,310 |
| Rock, dry.....do | 595,185 | .65 | 386,870 |
| Rock, artificially dry.....do | 1,144,352 | .75 | 1,083,264 |
| Clay.....do | 1,128,556 | .18 | 203,140 |
| Gravel.....do | 1,875,048 | .18 | 337,509 |
| Sand.....do | 7,192,600 | .18 | 1,294,668 |
| Earth.....do | 2,175,193 | .18 | 391,535 |
| Extra for lock: | | | |
| Earth.....do | 204,577 | .32 | 65,465 |
| Rock.....do | 167,970 | .60 | 100,782 |
| Diversion and levees | | | 310,306 |

*a* Per 1,000 feet.

TABLE No. 9.—*Oswego-Mohawk route, eastern division—Estimate of construction of 30-foot channel*—Continued.

SECTION NO. 6 (STATION 5651 TO STATION 6103), FROM ST. JOHNSVILLE TO CANAJOHARIE—Continued.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Right of way: | | | |
| Farm land ..... acres | 1,544 | $100.00 | $154,400 |
| Town land ..... do | 30 | 2,800.00 | 84,000 |
| Railroad changes ..... miles | 1.51 | ..... | 26,304 |
| Entrance of streams, submerged weirs ..... | ..... | ..... | 2,569 |
| Retaining wall ..... cubic yards | 110,813 | 4.00 | 443,252 |
| Slope wall ..... square yards | 248,701 | 1.10 | 273,571 |
| Back fill ..... cubic yards | 229,575 | .25 | 57,394 |
| Timber crib: | | | |
| Oak ..... feet B. M. | 50,880 | a50.00 | 2,544 |
| Hemlock ..... do | 3,350,514 | a23.00 | 77,062 |
| Pine ..... do | 1,044,806 | a30.00 | 31,344 |
| Stone fill ..... cubic yards | 58,500 | .60 | 35,100 |
| Iron bolts ..... pounds | 317,535 | .03 | 9,526 |
| Lock No. 15 ..... | ..... | ..... | 1,010,095 |
| Operating machinery ..... | ..... | ..... | 100,000 |
| Dams: | | | |
| Concrete ..... cubic yards | 22,494 | 6.00 | 134,964 |
| Excavation, earth ..... do | 50,210 | .50 | 25,105 |
| Cofferdam ..... | ..... | ..... | 14,500 |
| Bridge ..... | 1 | ..... | 92,250 |
| Total ..... | ..... | ..... | 7,929,829 |

SECTION NO. 7 (STATION 6103 TO STATION 6800), FROM CANAJOHARIE TO FULTONVILLE.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, wet ..... cubic yards | 32,970 | $2.00 | $65,940 |
| Rock, artificially dry ..... do | 399,964 | .75 | 299,973 |
| Clay and bowlders, dry ..... do | 475,667 | .20 | 95,133 |
| Clay ..... do | 2,892,628 | .18 | 520,673 |
| Gravel ..... do | 1,163,980 | .18 | 209,516 |
| Sand ..... do | 16,488,434 | .18 | 2,967,918 |
| Earth ..... do | 4,188,200 | .18 | 753,876 |
| Extra for lock: | | | |
| Earth ..... do | 496,970 | .32 | 159,030 |
| Rock ..... do | 10,842 | .50 | 5,421 |
| Diversion and levees ..... | ..... | ..... | 60,000 |
| Right of way: | | | |
| Farm land ..... acres | 2,422 | 100.00 | 242,200 |
| Town land ..... do | 96 | 3,193.00 | 306,528 |
| Railroad changes ..... miles | 3.64 | ..... | 40,560 |
| Entrance of streams, submerged weirs ..... | ..... | ..... | 4,252 |
| Retaining wall ..... cubic yards | 81,674 | 4.00 | 326,696 |
| Slope wall ..... square yards | 443,335 | 1.10 | 487,669 |
| Back fill ..... cubic yards | 547,683 | .25 | 136,921 |
| Timber crib: | | | |
| Oak ..... feet B. M. | 122,880 | a50.00 | 6,144 |
| Hemlock ..... do | 10,745,394 | a23.00 | 247,144 |
| Pine ..... do | 3,522,566 | a30.00 | 105,677 |
| Stone fill ..... cubic yards | 181,590 | .60 | 108,954 |
| Iron bolts ..... pounds | 1,286,180 | .03 | 38,585 |
| Lock No. 16 ..... | ..... | ..... | 1,015,283 |
| Operating machinery ..... | ..... | ..... | 100,000 |
| Dams: | | | |
| Concrete, dam and wing ..... cubic yards | 19,902 | 6.00 | 119,412 |
| Timber in foundation ..... feet B. M. | 1,191,000 | a22.00 | 26,202 |
| Piles in foundation ..... linear feet | 163,320 | .20 | 32,664 |
| Sheet piling in foundation ..... feet B. M. | 202,800 | a33.00 | 8,672 |
| Iron in foundation ..... pounds | 102,000 | .03 | 3,060 |
| Excavation, earth ..... cubic yards | 53,400 | .50 | 26,700 |
| Embankment ..... do | 3,700 | .15 | 555 |
| Cofferdam ..... | ..... | ..... | 25,000 |
| Bridges ..... | 2 | ..... | 180,054 |
| Total ..... | ..... | ..... | 8,726,412 |

a Per 1,000 feet.

TABLE No. 9.—*Oswego-Mohawk route, eastern division—Estimate of construction of 30-foot channel*—Continued.

SECTION NO. 8 (STATION 6800 TO STATION 7732), FULTONVILLE TO ROTTERDAM JUNCTION.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry ..... cubic yards.. | 398,163 | $0.65 | $258,806 |
| Rock, wet ..... do.... | 612,927 | 2.00 | 1,225,854 |
| Rock, artificially dry ..... do.... | 610,427 | .75 | 457,820 |
| Clay ..... do.... | 6,293,037 | .18 | 1,132,747 |
| Gravel ..... do.... | 13,755,344 | .18 | 2,475,962 |
| Sand ..... do.... | 15,912,153 | .18 | 2,864,188 |
| Quicksand ..... do.... | 176,790 | .18 | 31,822 |
| Earth ..... do.... | 6,316,712 | .18 | 1,137,008 |
| Extra for locks: | | | |
| Earth ..... cubic yards.. | 463,430 | .32 | 148,298 |
| Rock ..... do.... | 96,521 | .60 | 57,913 |
| Diversion and levees ..... | ..... | ..... | 47,000 |
| Right of way: | | | |
| Farm land ..... acres.. | 3,168 | 100.00 | 316,800 |
| Town land ..... do.... | 61 | 7,486.00 | 456,646 |
| Railroad changes ..... miles.. | 3.99 | ..... | 105,893 |
| Entrance of streams, submerged weirs ..... | ..... | ..... | 2,643 |
| Retaining wall ..... cubic yards.. | 90,244 | 4.00 | 360,976 |
| Slope wall ..... square yards.. | 623,737 | 1.10 | 686,111 |
| Back fill ..... cubic yards.. | 421,272 | .25 | 105,318 |
| Timber crib: | | | |
| Oak ..... feet B. M.. | 191,040 | *a* 50.00 | 9,552 |
| Hemlock ..... do.... | 16,746,154 | *a* 23.00 | 385,162 |
| Pine ..... do.... | 5,657,946 | *a* 30.00 | 169,738 |
| Stone fill ..... cubic yards.. | 282,590 | .60 | 169,554 |
| Iron bolts ..... pounds.. | 2,032,610 | .03 | 60,978 |
| Lock No. 17 ..... | ..... | ..... | 1,062,977 |
| Operating machinery ..... | ..... | ..... | 109,000 |
| Lock No. 18 ..... | ..... | ..... | 1,245,321 |
| Operating machinery ..... | ..... | ..... | 100,000 |
| Dam at Amsterdam: | | | |
| Concrete ..... cubic yards.. | 35,812 | 6.00 | 214,872 |
| Excavation, earth ..... do.... | 72,800 | .50 | 36,400 |
| Cofferdam ..... | ..... | ..... | 17,800 |
| Dam at Cranesville: | | | |
| Concrete ..... cubic yards.. | 17,325 | 6.00 | 103,950 |
| Timber in foundation ..... feet B. M.. | 1,116,720 | *a* 22.00 | 24,568 |
| Piles in foundation ..... linear feet.. | 154,140 | .20 | 30,828 |
| Sheet piling ..... feet B. M.. | 249,600 | *a* 33.00 | 8,237 |
| Iron ..... pounds.. | 100,000 | .03 | 3,000 |
| Excavation, earth ..... cubic yards.. | 40,800 | .50 | 20,400 |
| Cofferdam ..... | ..... | ..... | 11,000 |
| Bridges ..... | 3 | ..... | 538,943 |
| Steam ferry ..... | 1 | ..... | 20,000 |
| Total ..... | ..... | ..... | 16,205,085 |

SECTION NO. 9 (STATION 7732 TO STATION 8043), FROM ROTTERDAM JUNCTION TO 1 MILE NORTH OF SOUTH SCHENECTADY.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry ..... cubic yards.. | 560,525 | $0.60 | $336,315 |
| Hard material, dry ..... do.... | 1,338,299 | .30 | 401,490 |
| Clay ..... do.... | 1,240,789 | .18 | 223,342 |
| Gravel ..... do.... | 1,106,294 | .18 | 199,133 |
| Sand ..... do.... | 3,835,337 | .18 | 690,361 |
| Earth ..... do.... | 5,727,104 | .18 | 1,030,879 |
| Extra for lock, earth ..... cubic yards.. | 366,656 | .32 | 117,330 |
| Right of way: | | | |
| Farm land ..... acres.. | 1,593 | 100.00 | 159,300 |
| Town land ..... do.... | 36 | 2,600.00 | 93,600 |
| Retaining wall ..... cubic yards.. | 9,340 | 4.00 | 37,360 |
| Slope wall ..... square yards.. | 190,763 | 1.10 | 209,839 |
| Back fill ..... cubic yards.. | 280,761 | .25 | 70,190 |
| Core wall ..... do.... | 15,417 | 4.50 | 69,377 |
| Embankment ..... do.... | 1,046,767 | .15 | 157,015 |
| Timber crib: | | | |
| Hemlock ..... feet B. M.. | 6,990,900 | *a* 23.00 | 160,791 |
| Pine ..... do.... | 1,568,140 | *a* 30.00 | 47,044 |

*a* Per 1,000 feet.

TABLE NO. 9.—*Oswego-Mohawk route, eastern division—Estimate of construction of 30-foot channel*—Continued.

SECTION NO. 9 (STATION 7732 TO STATION 8043), FROM ROTTERDAM JUNCTION TO 1 MILE NORTH OF SOUTH SCHENECTADY—Continued.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Timber crib: | | | |
| Oak, feet B. M. | 88,776 | *a* $50.00 | $4,439 |
| Iron, pounds | 738,680 | .03 | 22,160 |
| Stone fill, cubic yards | 112,984 | .60 | 67,790 |
| Lock No. 19 | | | 965,777 |
| Operating machinery | | | 100,000 |
| Dams: | | | |
| Concrete, cubic yards | 32,040 | 6.00 | 192,240 |
| Concrete core wall, do | 9,000 | 4.50 | 40,500 |
| Timber in foundation, feet B. M. | 1,406,600 | *a* 22.00 | 30,945 |
| Piles in foundation, linear feet | 218,610 | .20 | 43,722 |
| Sheet piling in foundation, feet B. M. | 283,200 | *a* 33.00 | 9,346 |
| Iron, pounds | 132,000 | .03 | 3,960 |
| Excavation, cubic yards | 75,825 | .50 | 37,913 |
| Embankment, do | 32,900 | .15 | 4,935 |
| Cofferdam | | | 14,000 |
| Bridges | 2 | | 184,437 |
| Total | | | 5,725,530 |

SECTION NO. 10 (STATION 8043 TO STATION 8423), FROM 1 MILE NORTH OF SOUTH SCHENECTADY TO FRENCH MILLS.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry, cubic yards | 603,252 | $0.60 | $361,951 |
| Hardpan, do | 4,654,025 | .30 | 1,396,208 |
| Clay, do | 679,757 | .18 | 122,356 |
| Gravel, do | 339,879 | .18 | 61,178 |
| Sand, do | 1,168,794 | .18 | 210,383 |
| Earth, do | 253,788 | .18 | 45,682 |
| Long haul, shale, do | 7,334,260 | .60 | 4,400,556 |
| Long haul, quicksand, do | 4,007,249 | .17 | 681,232 |
| Long haul, clay, do | 3,259,155 | .17 | 554,056 |
| Long haul, gravel, do | 3,259,155 | .17 | 554,056 |
| Long haul, sand, do | 15,604,521 | .17 | 2,652,769 |
| Long haul, earth, do | 2,357,567 | .17 | 400,786 |
| Right of way: | | | |
| Farm land, acres | 1,516 | 100.00 | 151,600 |
| Town land, do | 7 | 500.00 | 3,500 |
| Entrance of streams | | | 30,294 |
| Retaining wall, cubic yards | 78,252 | 4.50 | 352,134 |
| Slope walls, square yards | 92,175 | 1.45 | 133,654 |
| Back fill, cubic yards | 616,210 | .25 | 154,053 |
| Timber crib: | | | |
| Oak, feet B. M. | 87,576 | *a* 50.00 | 4,379 |
| Hemlock, do | 7,428,272 | *a* 23.00 | 170,850 |
| Pine, do | 1,068,988 | *a* 30.00 | 32,070 |
| Stone fill, cubic yards | 113,519 | .60 | 68,111 |
| Iron bolts, pounds | 730,958 | .03 | 21,929 |
| Lock No. 20 | | | 884,446 |
| Operating machinery | | | 100,000 |
| Dam: | | | |
| Concrete, cubic yard | 1,548 | 6.00 | 9,288 |
| Cofferdam | | | 6,000 |
| Bridges | 8 | | 658,030 |
| Total | | | 14,221,551 |

SECTION NO. 11 (STATION 8423 TO STATION 8663), FROM FRENCH MILLS TO ROAD TO VOORHEESVILLE.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry, cubic yards | 318,913 | $0.60 | $191,348 |
| Hardpan, dry, do | 5,368,895 | .30 | 1,610,669 |
| Right of way, farm land, acres | 1,019 | 100.00 | 101,900 |
| Slope wall, square yards | 9,771 | 1.45 | 14,168 |
| Back fill, cubic yards | 378,981 | .25 | 94,745 |
| Timber crib: | | | |
| Oak, feet B. M. | 152,400 | *a* 50.00 | 7,620 |
| Hemlock, do | 15,550,642 | *a* 23.00 | 357,665 |

*a* Per 1,000 feet.

TABLE NO. 9.—*Oswego-Mohawk route, eastern division—Estimate of construction of 30-foot channel*—Continued.

SECTION NO. 11 (STATION 8423 TO STATION 8963), FROM FRENCH MILLS TO ROAD TO VOORHEESVILLE—Continued.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Timber crib—Continued. | | | |
| Pine ..... feet B. M | 1,949,308 | *a* $30.00 | $58,479 |
| Stone fill ..... cubic yards | 197,644 | .60 | 118,586 |
| Iron bolts ..... pounds | 1,430,686 | .03 | 42,921 |
| Lock No. 21 ..... | | | 966,258 |
| Operating machinery ..... | | | 100,000 |
| Locks Nos. 22 and 23 ..... | | | 3,114,687 |
| Operating machinery ..... | | | 175,000 |
| Dam: | | | |
| Concrete ..... cubic yards | 9,601 | 6.00 | 57,606 |
| Excavation, earth ..... do | 29,800 | .15 | 4,470 |
| Concrete ..... do | 60,696 | 6.00 | 364,176 |
| Excavation, earth ..... do | 99,000 | .15 | 14,850 |
| Bridges ..... | 2 | ..... | 194,212 |
| Total ..... | ..... | ..... | 7,589,360 |

SECTION NO. 12 (STATION 8963 TO STATION 8923), FROM ROAD TO VORHEESVILLE TO 1 MILE WEST OF NORMANSVILLE.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry ..... cubic yards | 5,281 | $0.60 | $3,169 |
| Clay ..... do | 4,037,641 | .15 | 605,646 |
| Sand ..... do | 1,345,880 | .15 | 201,882 |
| Right of way, farm land ..... acres | 4,334 | 100.00 | 433,400 |
| Slope wall ..... square yards | 36,771 | 1.45 | 53,318 |
| Bridges ..... | 2 | ..... | 194,212 |
| Total ..... | ..... | ..... | 1,491,627 |

SECTION NO. 13 (STATION 8923 TO STATION 9106+18.5), FROM 1 MILE WEST OF NORMANSVILLE TO HUDSON RIVER.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, hard, dry ..... cubic yards | 2,627,030 | $0.65 | $1,707,570 |
| Rock, dry ..... do | 537,516 | .60 | 322,510 |
| Clay ..... do | 6,954,046 | .15 | 1,043,107 |
| Sand ..... do | 661,638 | .15 | 99,246 |
| Earth ..... do | 451,681 | .15 | 67,752 |
| Right of way: | | | |
| Farm land ..... acres | 585 | 100.00 | 58,500 |
| Town land ..... do | 13 | 3,846.00 | 50,000 |
| Railroad changes ..... miles | 2 | ..... | 119,902 |
| Retaining wall ..... cubic yards | 7,504 | 4.50 | 33,768 |
| Slope wall ..... square yards | 28,733 | 1.45 | 41,663 |
| Back fill ..... cubic yards | 547,765 | .25 | 136,941 |
| Timber crib: | | | |
| Oak ..... feet B. M | 161,784 | *a* 50.00 | 8,089 |
| Hemlock ..... do | 18,789,595 | *a* 23.00 | 432,161 |
| Pine ..... do | 1,567,981 | *a* 30.00 | 47,039 |
| Stone fill ..... cubic yards | 273,784 | .60 | 164,270 |
| Iron bolts ..... pounds | 1,667,437 | .03 | 50,023 |
| Locks Nos. 24, 25, and 26 ..... | | | 4,720,697 |
| Operating machinery ..... | | | 225,000 |
| Locks Nos. 27, 28, 29, 30, and 31 ..... | | | 7,445,009 |
| Operating machinery ..... | | | 350,000 |
| Dam: | | | |
| Concrete ..... cubic yards | 44,495 | 6.00 | 266,970 |
| Excavation, earth ..... do | 34,900 | .15 | 5,235 |
| Concrete ..... do | 6,750 | 6.00 | 40,500 |
| Bridges ..... | 5 | ..... | 212,367 |
| Total ..... | ..... | ..... | 17,648,919 |

*a* Per 1,000 feet.

TABLE NO. 9.—*Oswego-Mohawk route, eastern division—Estimate of construction of 30-foot channel*—Continued.

SUMMARY.

| Section. | Station to station. | Total cost. |
|---|---|---|
| 1 | 4789+91.5 to 4848 | $535,431 |
| 2 | 4848 to 5118 | 6,512,731 |
| 3 | 5118 to 5175 | 6,068,726 |
| 4 | 5175 to 5260 | 857,859 |
| 5 | 5260 to 5651 | 8,136,131 |
| 6 | 5651 to 6103 | 7,929,829 |
| 7 | 6103 to 6800 | 8,726,412 |
| 8 | 6800 to 7732 | 16,205,085 |
| 9 | 7732 to 8043 | 5,725,530 |
| 10 | 8043 to 8423 | 14,221,551 |
| 11 | 8423 to 8663 | 7,589,360 |
| 12 | 8663 to 8923 | 1,491,627 |
| 13 | 8923 to 9106+18.5 | 17,648,919 |
| Grand total | | 102,249,191 |

TABLE NO. 10.—*Oswego-Mohawk route, eastern division—Estimate of construction of 21-foot channel.*

SECTION NO. 1 (STATION 4789+91.5 TO STATION 4848+00), FROM HERKIMER TO 1¼ MILES EAST OF HERKIMER.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Excavation: | | | |
| Gravel, cubic yards | 838,919 | $0.18 | $151,005 |
| Sand, do | 601,863 | .18 | 108,335 |
| Earth, do | 601,862 | .18 | 108,335 |
| Right of way, farm land, acres | 189 | 100.00 | 18,900 |
| Entrance of streams | | | 2,352 |
| Slope wall, square yards | 29,814 | 1.10 | 32,795 |
| Total | | | 421,722 |

SECTION NO. 2 (STATION 4848 TO STATION 5118), FROM 1¼ MILES EAST OF HERKIMER TO LITTLE FALLS.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry (quartzite), cubic yards | 342,786 | $0.75 | $257,090 |
| Rock, wet (quartzite), do | 137,078 | 2.50 | 342,695 |
| Rock, artificially dry (quartzite), do | 111,445 | 1.00 | 111,445 |
| Clay, do | 750,024 | .18 | 135,004 |
| Gravel, do | 504,467 | .18 | 90,804 |
| Sand, do | 3,263,024 | .18 | 587,344 |
| Earth, do | 1,481,095 | .18 | 266,597 |
| Diversion | | | 60,000 |
| Right of way: | | | |
| Farm land, acres | 868 | 100.00 | 86,800 |
| Town land, do | 5 | 14,286.00 | 71,430 |
| Railroad changes, miles | 3.05 | | 23,851 |
| Retaining wall, cubic yards | 50,355 | 4.00 | 201,420 |
| Slope wall, square yards | 116,720 | 1.10 | 128,392 |
| Back fill, cubic yards | 149,071 | .25 | 37,268 |
| Timber crib: | | | |
| Oak, feet B. M. | 103,440 | *a* 50.00 | 5,172 |
| Hemlock, do | 7,293,355 | *a* 23.00 | 167,747 |
| Pine, do | 1,616,445 | *a* 30.00 | 48,493 |
| Stone fill, cubic yards | 110,210 | .60 | 66,126 |
| Iron bolts, pounds | 785,255 | .03 | 23,558 |
| Lock No. 11 | | | 560,968 |
| Operating machinery | | | 100,000 |
| Dam: | | | |
| Concrete, dam and wing wall, cubic yards | 21,606 | 6.00 | 129,636 |
| Concrete, core wall, do | 10,000 | 4.50 | 45,000 |
| Excavation, earth, do | 53,630 | .18 | 9,653 |
| Embankment, do | 45,750 | .15 | 6,863 |
| Cofferdam | | | 12,800 |
| Total | | | 3,576,156 |

*a* Per 1,000 feet.

TABLE NO. 10.—*Oswego-Mohawk route, eastern division—Estimate of construction of 21-foot channel*—Continued.

SECTION NO. 3 (STATION 5118 TO STATION 5175), LITTLE FALLS.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Excavation, rock, dry (quartzite)...cubic yards. | 1,837,425 | $0.75 | $1,378,069 |
| Right of way: | | | |
| Farm land...acres. | 47 | 100.00 | 4,700 |
| Town land...do. | 37 | 22,124.00 | 818,588 |
| Retaining wall...cubic yards. | 54,405 | 4.00 | 217,620 |
| Timber crib: | | | |
| Oak...feet B. M. | 19,200 | a50.00 | 960 |
| Hemlock...do. | 920,400 | a23.00 | 21,169 |
| Pine...do. | 367,200 | a30.00 | 11,016 |
| Stone fill...cubic yards. | 9,660 | .60 | 5,796 |
| Iron bolts...pounds. | 79,500 | .03 | 2,385 |
| Locks Nos. 12 and 13 | | | 2,434,589 |
| Operating machinery | | | 175,000 |
| Dam: | | | |
| Concrete, dam and wing walls...cubic yards. | 5,150 | 6.00 | 30,900 |
| Excavation, earth...do. | 6,610 | .18 | 1,190 |
| Cofferdam | | | 27,000 |
| Bridge | 1 | | 65,382 |
| Total | | | 5,195,364 |

SECTION NO. 4 (STATION 5175 TO STATION 5260), FROM LITTLE FALLS TO THREE-FOURTHS OF A MILE BELOW SUSPENSION BRIDGE.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, hard, artificially dry...cubic yards. | 147,717 | $1.00 | $147,717 |
| Sand...do. | 1,674,046 | .18 | 301,328 |
| Diversion | | | 10,000 |
| Right of way, farm land...acres. | 293 | 100.00 | 29,300 |
| Slope wall...square yards. | 73,789 | 1.10 | 81,168 |
| Timber crib: | | | |
| Oak...feet B. M. | 35,040 | a50.00 | 1,752 |
| Hemlock...do. | 2,689,740 | a23.00 | 61,865 |
| Pine...do. | 906,300 | a30.00 | 27,189 |
| Stone fill...cubic yards. | 43,625 | .60 | 26,175 |
| Iron bolts...pounds. | 314,525 | .03 | 9,436 |
| Bridge | 1 | | 90,666 |
| Total | | | 786,596 |

SECTION NO. 5 (STATION 5260 TO STATION 5651), FROM THREE-FOURTHS OF A MILE BELOW SUSPENSION BRIDGE TO ST. JOHNSVILLE.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry...cubic yards. | 861,759 | $0.65 | $560,143 |
| Extra for lock, rock, dry...do. | 82,804 | .60 | 49,682 |
| Rock, artificially dry...do. | 906,112 | .75 | 679,584 |
| Clay...do. | 242,450 | .18 | 43,641 |
| Gravel...do. | 1,708,542 | .18 | 307,538 |
| Sand...do. | 4,298,096 | .18 | 773,657 |
| Earth...do. | 1,523,982 | .18 | 274,317 |
| Earth, extra for lock...do. | 93,793 | .32 | 30,014 |
| Diversion | | | 200,000 |
| Right of way, farm land...acres. | 2,200 | 100.00 | 220,000 |
| Railroad changes...miles. | 4.22 | | 73,795 |
| Entrance of streams | | | 2,006 |
| Retaining wall...cubic yards. | 135,696 | 4.00 | 542,784 |
| Slope wall...square yards. | 128,745 | 1.10 | 141,620 |
| Back fill...cubic yards. | 228,510 | .25 | 57,128 |
| Timber crib: | | | |
| Oak...feet B. M. | 102,240 | a50.00 | 5,112 |
| Hemlock...do. | 5,292,820 | a23.00 | 121,735 |
| Pine...do. | 2,747,520 | a30.00 | 82,426 |
| Stone fill...cubic yards. | 102,050 | .60 | 61,230 |
| Iron...pounds. | 688,192 | .03 | 20,646 |
| Lock No. 14 | | | 684,348 |
| Operating machinery | | | 140,000 |
| Dam: | | | |
| Concrete, dam and wing wall...cubic yards. | 35,960 | 6.00 | 215,760 |
| Excavation, earth...do. | 68,944 | .50 | 34,472 |
| Cofferdam | | | 20,000 |
| Bridge | 1 | | 71,092 |
| Total | | | 5,372,730 |

a Per 1,000 feet.

TABLE NO. 10.—*Oswego-Mohawk route, eastern division—Estimate of construction of 21-foot channel*—Continued.

SECTION NO. 6 (STATION 5651 TO STATION 6103), FROM ST. JOHNSVILLE TO CANAJOHARIE.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry ..... cubic yards.. | 96,214 | $0.65 | $62,539 |
| Rock, dry, extra for lock ..... do.... | 73,814 | .60 | 44,288 |
| Rock, wet ..... do.... | 88,429 | 2.00 | 176,858 |
| Rock, artificially dry ..... do.... | 567,710 | .75 | 425,783 |
| Clay ..... do.... | 1,122,065 | .18 | 201,972 |
| Gravel ..... do.... | 2,057,292 | .18 | 370,313 |
| Sand ..... do.... | 7,180,540 | .18 | 1,292,497 |
| Earth ..... do.... | 2,304,549 | .18 | 414,819 |
| Earth, extra for lock ..... do.... | 96,979 | .32 | 31,033 |
| Diversion ..... | | | 185,000 |
| Right of way: | | | |
| Farm land ..... acres.. | 1,544 | 100.00 | 154,400 |
| Town land ..... do.. | 30 | 2,800.00 | 84,000 |
| Railroad changes ..... miles.. | 1.51 | | 26,304 |
| Entrance of streams ..... | | | 2,569 |
| Retaining wall ..... cubic yards.. | 33,560 | 4.00 | 134,240 |
| Slope wall ..... square yards.. | 270,089 | 1.10 | 297,098 |
| Back fill ..... cubic yards.. | 120,784 | .25 | 30,196 |
| Timber crib: | | | |
| Oak ..... feet B. M.. | 122,880 | *a* 50.00 | 6,144 |
| Hemlock ..... do.... | 5,388,910 | *a* 23.00 | 123,945 |
| Pine ..... do.... | 3,094,800 | *a* 30.00 | 92,844 |
| Stone fill ..... cubic yards.. | 106,080 | .60 | 63,648 |
| Iron bolts ..... pounds.. | 732,467 | .03 | 21,974 |
| Lock No. 15 ..... | | | 615,861 |
| Operating machinery ..... | | | 100,000 |
| Dam: | | | |
| Concrete, dam and wing wall ..... cubic yards.. | 22,494 | 6.00 | 134,964 |
| Excavation, earth ..... do.... | 50,210 | .50 | 25,105 |
| Cofferdam ..... | | | 14,500 |
| Bridge ..... | 1 | | 90,770 |
| Total ..... | | | 5,223,664 |

SECTION NO. 7 (STATION 6103 TO STATION 6800), FROM CANAJOHARIE TO FULTONVILLE.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, wet ..... cubic yards.. | 15,199 | $2.00 | $30,398 |
| Rock, artificially dry ..... do.... | 181,404 | .75 | 136,053 |
| Clay and bowlders, dry ..... do.... | 475,667 | .20 | 95,133 |
| Clay ..... do.... | 2,892,628 | .18 | 520,673 |
| Gravel ..... do.... | 1,115,445 | .18 | 200,780 |
| Sand ..... do.... | 15,000,066 | .18 | 2,700,012 |
| Earth ..... do.... | 4,166,681 | .18 | 750,003 |
| Earth, extra for lock ..... do.... | 280,120 | .32 | 89,638 |
| Diversion ..... | | | 55,000 |
| Right of way: | | | |
| Farm land ..... acres.. | 2,422 | 100.00 | 242,200 |
| Town land ..... do.... | 96 | 3,193.00 | 306,528 |
| Railroad changes ..... miles.. | 3.64 | | 40,560 |
| Entrance of streams ..... | | | 4,252 |
| Retaining wall ..... cubic yards.. | 49,215 | 4.00 | 196,860 |
| Slope wall ..... square yards.. | 479,311 | 1.10 | 527,242 |
| Back fill ..... cubic yards.. | 330,371 | .25 | 82,593 |
| Timber crib: | | | |
| Oak ..... feet B. M.. | 158,400 | *a* 50.00 | 7,920 |
| Hemlock ..... do.... | 9,900,000 | *a* 23.00 | 227,700 |
| Pine ..... do.... | 3,980,800 | *a* 30.00 | 119,424 |
| Stone fill ..... cubic yards.. | 171,000 | .60 | 102,600 |
| Iron bolts ..... pounds.. | 1,223,760 | .03 | 36,713 |
| Lock No. 16 ..... | | | 721,484 |
| Operating machinery ..... | | | 100,000 |
| Dam: | | | |
| Concrete, dam and wing wall ..... cubic yards.. | 19,902 | 6.00 | 119,412 |
| Timber in foundation ..... feet B. M.. | 1,191,000 | *a* 22.00 | 26,202 |
| Piles in foundation ..... linear feet.. | 163,320 | .20 | 32,664 |
| Sheet piling in foundation ..... feet B. M.. | 262,800 | *a* 33.00 | 8,673 |
| Iron ..... pounds.. | 102,000 | .03 | 3,060 |
| Excavation, earth ..... cubic yards.. | 53,400 | .50 | 26,700 |
| Embankment ..... do.... | 3,700 | .15 | 555 |
| Cofferdam ..... | | | 25,000 |
| Bridges ..... | 2 | | 160,698 |
| Total ..... | | | 7,696,730 |

*a* Per 1,000 feet.

TABLE No. 10.—*Oswego-Mohawk route, eastern division—Estimate of construction of 21-foot channel*—Continued.

SECTION NO. 8 (STATION 680 TO STATION 7320, FROM FULTONVILLE TO ROTTERDAM JUNCTION.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Excavation: | | | |
| Rock, extra for lock ..... cubic yards | 29,139 | $0.60 | $17,483 |
| Rock, dry ..... do | 398,163 | .65 | 258,806 |
| Rock, wet ..... do | 612,927 | 2.00 | 1,225,854 |
| Rock, artificially dry ..... do | 395,271 | .75 | 296,453 |
| Clay ..... do | 6,293,037 | .18 | 1,132,747 |
| Gravel ..... do | 13,755,344 | .18 | 2,475,962 |
| Sand ..... do | 15,251,930 | .18 | 2,745,347 |
| Quicksand ..... do | 176,790 | .18 | 31,822 |
| Earth ..... do | 6,316,712 | .18 | 1,137,008 |
| Earth, extra for locks ..... do | 245,871 | .32 | 78,679 |
| Diversion ..... | | | 47,000 |
| Right of way: | | | |
| Farm land ..... acres | 3,168 | 100.00 | 316,800 |
| Town land ..... do | 61 | 7,486.00 | 456,646 |
| Railroad changes ..... miles | 3.99 | | 105,893 |
| Entrance of streams ..... | | | 2,643 |
| Retaining wall ..... cubic yards | 66,717 | 4.00 | 266,868 |
| Slope wall ..... square yards | 623,737 | 1.10 | 686,111 |
| Back fill ..... cubic yards | 279,672 | .25 | 69,918 |
| Timber crib: | | | |
| Oak ..... feet B. M. | 272,980 | *a* 50.00 | 13,649 |
| Hemlock ..... do | 17,238,000 | *a* 23.00 | 396,474 |
| Pine ..... do | 6,626,740 | *a* 30.00 | 198,802 |
| Stone fill ..... cubic yards | 271,010 | .60 | 162,606 |
| Iron bolts ..... pounds | 1,984,060 | .03 | 59,522 |
| Lock No. 17 ..... | | | 648,475 |
| Operating machinery ..... | | | 100,000 |
| Lock No. 18 ..... | | | 765,818 |
| Operating machinery ..... | | | 100,000 |
| Dam at Amsterdam: | | | |
| Concrete, dam and wing wall ..... cubic yards | 35,812 | 6.00 | 214,872 |
| Excavation, earth ..... do | 72,800 | .50 | 36,400 |
| Cofferdam ..... | | | 17,800 |
| Dam at Cranesville: | | | |
| Concrete ..... cubic yards | 17,325 | 6.00 | 103,950 |
| Timber in foundation ..... feet B. M. | 1,116,720 | *a* 22.00 | 24,567 |
| Piles in foundation ..... linear feet | 154,140 | .20 | 30,828 |
| Sheet piling foundation ..... feet B. M. | 249,600 | *a* 33.00 | 8,237 |
| Iron ..... pounds | 100,060 | .03 | 3,000 |
| Excavation, earth ..... cubic yards | 40,800 | .50 | 20,400 |
| Cofferdam ..... | | | 11,000 |
| Bridges ..... | 3 | | 523,693 |
| Steam ferry ..... | 1 | | 20,000 |
| Total ..... | | | 14,812,433 |

SECTION NO. 9 (STATION 7732 TO STATION 8043), FROM ROTTERDAM JUNCTION TO 1 MILE NORTH OF SOUTH SCHENECTADY.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry ..... cubic yards | 333,953 | $0.60 | $200,372 |
| Hardpan ..... do | 488,537 | .30 | 146,561 |
| Clay ..... do | 994,497 | .18 | 179,009 |
| Gravel ..... do | 1,325,996 | .18 | 238,679 |
| Sand ..... do | 1,657,495 | .18 | 298,349 |
| Earth ..... do | 1,988,989 | .18 | 358,018 |
| Earth, extra for lock ..... do | 206,095 | .32 | 65,950 |
| Right of way: | | | |
| Farm land ..... acres | 1,593 | 100.00 | 159,300 |
| Town land ..... do | 36 | 2,600.00 | 93,600 |
| Retaining wall ..... cubic yards | 3,818 | 4.00 | 15,272 |
| Core wall in embankments ..... do | 15,417 | 4.50 | 69,377 |
| Slope wall ..... square yards | 197,859 | 1.10 | 217,645 |
| Back fill ..... cubic yards | 158,169 | .25 | 39,542 |
| Embankment ..... do | 1,033,426 | .15 | 155,014 |
| Timber crib: | | | |
| Oak ..... feet B. M. | 93,396 | *a* 50.00 | 1,667 |
| Hemlock ..... do | 5,354,740 | *a* 23.00 | 123,159 |
| Pine ..... do | 1,568,140 | *a* 30.00 | 47,044 |
| Stone fill ..... cubic yards | 605,394 | .60 | 363,236 |
| Iron bolts ..... pounds | 89,246 | .03 | 2,677 |
| Lock No. 19 ..... | | | 629,650 |
| Operating machinery ..... | | | 100,000 |
| Dam: | | | |
| Concrete, dam and wing wall ..... cubic yards | 32,040 | 6.00 | 192,240 |
| Concrete, core wall ..... do | 9,000 | 4.50 | 40,500 |

*a* Per 1,000 feet.

TABLE No. 10.—*Oswego-Mohawk route, eastern division—Estimate of construction of 21-foot channel*—Continued.

STATION NO. 9 (STATION 7732 TO STATION 8043), FROM ROTTERDAM JUNCTION TO 1 MILE NORTH OF SOUTH SCHENECTADY—Continued.

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Dam—Continued. | | | |
| Timber in foundation ..... feet B. M. | 1,406,600 | a $22.00 | $30,945 |
| Piles in foundation ..... linear feet. | 218,610 | .20 | 43,722 |
| Sheet piling in foundation ..... feet B. M. | 283,200 | a 33.00 | 9,346 |
| Iron ..... pounds. | 132,000 | .03 | 3,960 |
| Excavation, earth ..... cubic yards. | 75,825 | .50 | 37,913 |
| Embankment ..... do | 32,900 | .15 | 4,935 |
| Cofferdam ..... | ..... | ..... | 14,000 |
| Bridges ..... | 2 | ..... | 156,602 |
| Total ..... | ..... | ..... | 4,041,284 |

SECTION NO. 10 (STATION 8043 TO STATION 8423), FROM 1 MILE NORTH OF SOUTH SCHENECTADY TO FRENCH MILLS.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock ..... cubic yards. | 238,237 | $0.60 | $142,942 |
| Hardpan ..... do | 3,645,077 | .30 | 1,093,523 |
| Clay ..... do | 470,334 | .18 | 84,660 |
| Gravel ..... do | 135,167 | .18 | 24,330 |
| Sand ..... do | 954,660 | .18 | 171,839 |
| Earth ..... do | 149,159 | .18 | 26,849 |
| Rock, long haul ..... do | 5,935,815 | .60 | 3,561,489 |
| Clay, long haul ..... do | 2,954,860 | .17 | 502,326 |
| Gravel, long haul ..... do | 3,357,607 | .17 | 570,793 |
| Sand, long haul ..... do | 13,986,595 | .17 | 2,377,721 |
| Earth, long haul ..... do | 1,816,949 | .17 | 308,881 |
| Quicksand, long haul ..... do | 3,123,702 | .17 | 531,029 |
| Right of way: | | | |
| Farm land ..... acres. | 1,516 | 100.00 | 151,600 |
| Town land ..... do | 7 | 500.00 | 3,500 |
| Entrance of streams ..... | ..... | ..... | 30,294 |
| Retaining walls ..... cubic yards. | 18,682 | 4.50 | 84,069 |
| Slope walls ..... square yards. | 118,512 | 1.45 | 171,842 |
| Back fill ..... cubic yards. | 284,666 | .25 | 71,167 |
| Timber cribs: | | | |
| Oak ..... feet B. M. | 86,160 | a 50.00 | 4,308 |
| Hemlock ..... do | 5,382,440 | a 23.00 | 123,796 |
| Pine ..... do | 1,060,900 | a 30.00 | 31,827 |
| Stone fill ..... cubic yards. | 81,750 | .60 | 49,050 |
| Iron bolts ..... pounds. | 557,880 | .03 | 16,736 |
| Lock No. 20 ..... | ..... | ..... | 577,209 |
| Operating machinery ..... | ..... | ..... | 100,000 |
| Dam: | | | |
| Concrete dam ..... cubic yards. | 1,548 | 6.00 | 9,288 |
| Cofferdam ..... | ..... | ..... | 6,000 |
| Bridges ..... | 8 | ..... | 609,278 |
| Total ..... | ..... | ..... | 11,436,346 |

SECTION NO. 11 (STATION 8423 TO STATION 8863), FROM FRENCH MILLS TO ROAD TO VOORHEESVILLE.

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Rock, dry ..... cubic yards. | 160,883 | $0.60 | $96,530 |
| Hardpan, dry ..... do | 4,151,268 | .30 | 1,245,380 |
| Right of way, farm land ..... acres. | 1,019 | 100.00 | 110,900 |
| Slope wall ..... square yards. | 14,658 | 1.45 | 21,254 |
| Back fill ..... cubic yards. | 212,725 | .25 | 53,181 |
| Timber crib: | | | |
| Oak ..... feet B. M. | 149,520 | a 50.00 | 7,476 |
| Hemlock ..... do | 9,862,660 | a 23.00 | 226,841 |
| Pine ..... do | 1,891,000 | a 30.00 | 56,730 |
| Stone fill ..... cubic yards. | 142,010 | .60 | 85,206 |
| Iron bolts ..... pounds. | 1,051,620 | .03 | 31,549 |
| Lock No. 21 ..... | ..... | ..... | 728,626 |
| Operating machinery ..... | ..... | ..... | 100,000 |
| Locks Nos. 22 and 23 ..... | ..... | ..... | 2,172,165 |
| Operating machinery ..... | ..... | ..... | 175,000 |
| Dam: | | | |
| Concrete dam ..... cubic yards. | 9,601 | 6.00 | 57,606 |
| Excavation, earth ..... do | 29,800 | .15 | 4,470 |
| Concrete dam ..... do | 60,696 | 6.00 | 364,176 |
| Excavation, earth ..... do | 99,000 | .15 | 14,850 |
| Bridges ..... | 2 | ..... | 162,189 |
| Total ..... | ..... | ..... | 5,714,120 |

a Per 1,000 feet.

TABLE NO. 10.—*Oswego-Mohawk route, eastern division—Estimate of construction of 21-foot channel*—Continued.

SECTION NO. 12 (STATION 8063 TO STATION 8925, FROM ROAD TO VOORHEESVILLE TO 1 MILE WEST OF NORMANSVILLE.

| | Quantity. | Cost per unit | Total. |
|---|---|---|---|
| **Excavation:** | | | |
| Clay, cubic yards | 3,292,919 | $0.15 | $493,938 |
| Sand, do | 1,097,639 | .15 | 164,646 |
| Right of way, farm land, acres | 4,334 | 100.00 | 433,460 |
| Slope wall, square yards | 44,479 | 1.45 | 64,495 |
| Bridges | 2 | ..... | 162,180 |
| Total | | | 1,318,659 |

SECTION NO. 13 (STATION 8925 TO STATION 9106+18.5, FROM ROAD TO VOORHEESVILLE TO HUDSON RIVER.

| | | | |
|---|---|---|---|
| **Excavation:** | | | |
| Rock, hard, dry, cubic yards | 2,049,245 | $0.65 | $1,332,009 |
| Do, do | 222,083 | .60 | 133,250 |
| Clay, do | 5,532,532 | .15 | 829,880 |
| Sand, do | 386,446 | .15 | 57,967 |
| Earth, do | 278,737 | .15 | 41,811 |
| **Right of way:** | | | |
| Farm land, acres | 585 | 100.00 | 58,500 |
| Town land, do | 13 | 3,846.00 | 50,000 |
| Railroad changes, miles | 2 | ..... | 119,902 |
| Retaining walls, cubic yards | 2,636 | 4.50 | 11,862 |
| Slope wall, square yards | 39,234 | 1.45 | 56,889 |
| Back fill, cubic yards | 311,823 | .25 | 77,956 |
| **Timber crib:** | | | |
| Oak, feet B. M. | 188,880 | *a* 50.00 | 9,444 |
| Hemlock, do | 17,527,041 | *a* 23.00 | 403,122 |
| Pine, do | 2,275,805 | *a* 30.00 | 68,274 |
| Stone filling, cubic yards | 260,472 | .60 | 156,283 |
| Iron bolts, pounds | 1,593,976 | .03 | 47,819 |
| Locks Nos. 24, 25, and 26 | ..... | ..... | 3,065,295 |
| Operating machinery | ..... | ..... | 225,000 |
| Locks Nos. 27, 28, 29, 30, and 31 | ..... | ..... | 4,533,709 |
| Operating machinery | ..... | ..... | 350,000 |
| **Dam:** | | | |
| Concrete dam, cubic yards | 44,495 | 6.00 | 266,970 |
| Excavation, earth, do | 34,500 | .15 | 5,235 |
| Concrete, do | 6,750 | 6.00 | 40,500 |
| Bridges | 5 | ..... | 179,489 |
| Total | ..... | ..... | 12,121,236 |

*a* Per 1,000 feet.

SUMMARY.

| Section. | Station. | Total cost. |
|---|---|---|
| 1 | 4789+91.5 to 4848 | $421,732 |
| 2 | 4848 to 5118 | 3,676,156 |
| 3 | 5118 to 5175 | 5,195,364 |
| 4 | 5175 to 5250 | 768,596 |
| 5 | 5250 to 5651 | 5,372,730 |
| 6 | 5651 to 6163 | 5,223,684 |
| 7 | 6163 to 6800 | 7,696,730 |
| 8 | 6800 to 7732 | 14,812,133 |
| 9 | 7732 to 8043 | 4,041,284 |
| 10 | 8043 to 8423 | 11,196,346 |
| 11 | 8423 to 8963 | 5,714,120 |
| 12 | 8963 to 8925 | 1,318,659 |
| 13 | 8925 to 9106+18.5 | 12,121,236 |
| Grand total | | 77,716,740 |

In closing this report I desire to express to each member of the United States Board of Engineers on Deep Waterways my full appre-

ciation of the universal courtesy at all times extended to me during the progress of this work, and the full liberty given in the selection of my assistants, and discretion allowed in obtaining the information desired.

I also desire to take this occasion to state my indorsement and hearty cooperation in the wisdom of the suggestions and instructions as issued from time to time by this Board, as so greatly facilitating the obtaining of the results desired.

In view of the large number of men employed at different times, special mention can not be made of each, but I desire to thank each one and state my full appreciation of the value of the services rendered and the care, zeal, energy, and interest in the work as displayed by each employee, and which so largely contributed to, I think I can state, its successful completion. The names of those who filled the more important positions in the field and office are: John McComb, James J. Overn, J. W. Paxton, E. M. Durham, jr., C. E. Pelz, and E. C. Reynolds, instrument men; A. D. Raymond, level man; W. H. Breen, superintendent of borings; Oliver B. Harden and H. Tracy Fisher, draftsmen, and Heningham Gordon, recorder.

Respectfully,

D. J. HOWELL,
*Assistant Engineer.*

The BOARD OF ENGINEERS ON DEEP WATERWAYS.

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## APPENDIX NO. 15.

### TIDAL HUDSON.

DETROIT, MICH., *August 4, 1899.*

GENTLEMEN: I herewith very respectfully submit to you this report pertaining to surveys and borings of the Hudson River and approximate estimate of the cost of improvement from the State dam at Troy, N. Y., to the Atlantic Ocean.

First. For a channel varying from 300 to 600 feet in width, with a depth of 21 feet below low water.

Second. For a channel varying from 300 to 600 feet in width, with a depth of 30 feet below low water.

The Hudson River is an arm of the sea, extending inland 150 miles, and the general direction is north and south.

Extensive improvements have been made in the past by the State of New York and also by the Federal Government, and at present a 12-foot channel is maintained between New Baltimore and Broadway, Troy, N. Y. Between New Baltimore and Hudson City no improvements were necessary to maintain the 12-foot channel, but a dike has been constructed by the Federal Government closing up the channel

west of Bronk Island, and the heads of Light-house and Coxsackie islands have been protected from abrasion by pile dikes. During the dry season the stage of the river is largely dependent upon the tidal flow, and the ebb and flood currents are well defined in their proper directions.

The State dam at Troy, N. Y., is a division between the tidal and nontidal sections of the river, and during the dry season of 1897 the mean rise and fall of tides at that point was 1.49 feet. During ordinary stages of the river above the dam, when the river discharges an average quantity of water, the flood currents are not so well defined, but the ebb currents are still plainly marked. During freshets the tidal action is lost sight of entirely, and during ordinary spring freshets the river rises from 6 to 8 feet above mean low water.

The highest recorded stage of water at Albany, N. Y., caused by rainfall alone, occurred in October, 1869, the rise in the river being 19 feet above mean low water. The highest known stage of the river at Albany occurred in February, 1857, and was caused by an ice gorge at Van Wies Point, and is recorded at 22 feet above mean low water. The greatest known depth of water in recent years on the crest of the dam at Troy, N. Y., occurred March 1, 1896, and is recorded as 9.92 feet, making an elevation of high water of 23.4 feet. It will not be necessary, however, to dwell upon the high-water problem below the State dam, since the deepening of the channel would relieve that condition to a great extent.

## LOW WATER.

It is problematical how much the increased area of channel will decrease the stage of mean low water at the State dam in Troy, N. Y. During an extreme low stage of the Hudson River no water runs over the dam at all, and the only supply which the tidal section of the river receives during that time is water supplied by lockage from the canal, leakage, and through the water wheels. During this time the discharge is approximately between 3,000 and 4,000 cubic feet per second. The plane of mean low water of 1897 at the State dam is 0.37 foot lower than the mean low-water plane of 1876. At Green Island a difference of 0.59 foot is recorded between the two planes in the same direction, and at Albany the mean low-water plane of 1897 is 0.05 foot lower than the plane of mean low water of 1876.

In establishing the grade line upon which this estimate is based I assume that the elevation of extreme low water at the State dam, after the improvements are made, will be +1.23 feet and at Greenbush +0.24 foot. The distance between these two points is 8.24 miles, making the slope 0.12 foot per mile, approximately. At Stuyvesant, the elevation of low water is —0.18 foot, and the low-water stage there will not be affected by the improvements contemplated.

The distance between Greenbush and Stuyvesant is 17.22 miles, and the total slope is 0.42 foot between these two points. Between Stuyvesant and Hudson City the stage of low water will not be affected by any improvements, and quantities were computed for a 21 and 30 foot depth of channel, respectively, below this plane.

Very reliable elevations of low water could not be obtained below Coxsackie during the time the survey was made, on account of the continuous freshets which affected the river in the autumn of 1898 and spring of 1899. In May, 1899, elevations of —0.77 foot were obtained by staff-gauge readings at Hudson City during ebb tide, and approximate quantities were based on this elevation and the elevation, —0.18 foot, at Stuyvesant.

It will be necessary, however, to investigate the stage of low water more thoroughly, and if necessary modify the grade line upon which this approximate estimate is based before the contemplated improvements are undertaken.

TIDES.

[Deduced from information obtained from Mr. R. H. Talcott, United States assistant engineer, Albany, N. Y.]

| Location. | Mean high tide. | Mean tide. | Mean low tide. | Mean rise and fall of tide. | Year. |
|---|---|---|---|---|---|
| State Dam | +4.64 | +3.90 | +3.15 | 1.49 | 1897 |
| Covill Folly Light | +4.29 | +2.83 | +1.36 | 2.93 | 1897 |
| Albany | +4.09 | +2.67 | +1.24 | 2.85 | 1897 |
| Castleton | +3.61 | +2.30 | +0.99 | 2.62 | 1876 |
| New Baltimore | +3.27 | +1.67 | +0.07 | 3.20 | 1876 |
| Stuyvesant Light | +3.02 | +1.43 | −0.18 | 3.20 | 1876 |
| Hudson | +3.25 | +1.25 | −0.75 | 4.00 | 1899 |
| Germantown | +3.20 | +1.20 | −0.80 | 4.00 | 1899 |

SURVEYS.

In general, the method employed in making the survey was in accordance with the instructions to field parties, Appendix No. 9.

Before starting on the survey, observations were made on Polaris and a true azimuth established. A base line was then run from the Congress Street Bridge at Troy, N. Y., starting with station 0, at the origin of the base line for the Oswego route, eastern division. This line was carried across the Hudson River to the Troy side and extended south to a point about 1½ miles below Hudson City, and connected with triangulation point 273, commonly known as "Wisnall," of the New York State triangulation system, which is equal to base line station 1885+94.63 of the Hudson River survey.

As the base line was advanced observations for azimuth were made, whenever possible, every 5 miles, corrections for easting and westing were applied, and instrumental error found and distributed. The latter, however, never exceeded 3 feet and generally fell within 1 foot.

After the base line had been extended for some distance the levels were carried along by the same party, benches being established

every mile, approximately, and then the shore-line survey was taken up.

The latter consisted entirely of a stadia survey, the closing error for distance being limited to 1 foot in 500 feet and error in elevation 0.5 foot per circuit. No difficulty was found in keeping well within these limits. All stadia circuits were connected with the base line, and coordinates of stadia hubs were computed and referred to the origin of the circuit.

The shore-line survey extended from the State dam at Troy, N. Y., south to a point about 1½ miles below the city of Hudson, the total distance being approximately 37 miles. From the city of Hudson to Livingston Creek, a distance of 5.1 miles, a 30-foot channel already exists, as indicated on the Coast Survey charts, and no detailed surveys have been made covering this stretch. The survey was taken up again, however, at Livingston Creek, and extended south a distance of 4.4 miles to a point below Germantown. Covering this stretch soundings were taken on ranges 500 feet apart, but no extensive borings were taken. Occasionally the bed of the river was tested by using a half-inch gas pipe, pointed on one end, and forcing it down by hand to a distance several feet below the bottom of the proposed channel. The material encountered was a fine sand. The river was also examined near Barrytown and Rhinebeck. At Barrytown an estimate was made for dredging a channel about 3,600 feet long across the bar between the east and west channels for the 30-foot canal. No work is required for the 21-foot canal. At Rhinebeck the required depth was found, and no improvements will be necessary. An estimate was made for widening and straightening the 30-foot channel near Sycamore Point. The data for this purpose was taken from the Coast Survey charts.

## LEVELS.

All elevations in connection with this survey are referred to the plane of mean tide at Sandy Hook, and depend upon the elevation +14.73 of the Greenbush bench mark.

The method employed in transferring levels from this bench was as follows:

Duplicate lines of levels were run, backsights and foresights never exceeding 250 feet in length, and if the error exceeded 0.05 feet $\times$ $\sqrt{\text{distance in miles}}$ between bench marks, or from the origin of levels to any bench mark, the levels were rerun to bring the error within the prescribed limits.

## SOUNDINGS.

Soundings were taken on ranges approximately 300 feet apart, established by the sounding party, and subsequently located by the stadia party.

The method employed in taking soundings was as follows:

A flagman was placed at one end of the range, and it was his duty to keep the boat on range, as nearly as possible. Soundings were taken at from ten to thirty seconds intervals, depending upon the depth of the water, and were located by azimuths taken at minute intervals. Only one instrument was used, the location of the sounding being the intersection of the azimuth line with the range line. Generally a 10-pound lead was employed in taking soundings.

This method was very satisfactory. The boat used for that purpose, being supplied with a rudder, could be kept on range very closely, and the error in locating soundings would not exceed the limits of the plotting.

BORINGS.

In order to ascertain the character of material to be excavated, extensive borings have been made at intervals of 1,000 feet or less, and in every case where borings were located within the limits of the proposed channel they are carried below the depth of excavation or to the rock surface. The rock found in the Hudson River is what is known as Hudson River shale. The other material met with in the river consisted of bowlders, gravel, coarse and fine sand, clay, and silt.

I think that all the material to be removed, with the exception of the rock and bowlders, can be handled by pumps. In all, 1,385 borings were made, with a total of 28,965 feet of driving, at a cost of 25.11 cents per linear foot, including the cost of plant. Borings were taken on the sounding ranges and were located by intersections, stadia distances, or by direct measurements from the ends of the ranges.

Nearly all the borings relating to the investigation of the Hudson River below the State dam at Troy, N. Y., were taken from a catamaran and scows constructed for that purpose, and the method employed was as follows:

The crew for each boring outfit generally consisted of 1 foreman and 3 laborers. Two and one-half inch pipe, commercially known as "2½-inch R. H. flush-joint casing," manufactured in lengths from 1 to 10 feet, was lowered to the bed of the river, and hollow rods, commonly known as "B drill rods," with a cross bit attached, were inserted into the casing, the upper end of the rod being connected with a hand force pump, which was kept on the scow.

It was the duty of one man to work the pump and force water through the drill rods, while the other worked the drill by hand. The drill loosened the material, which was then forced upward through the casing. As the drill advanced into the bed of the river it was followed by the casing.

Quite frequently very formidable obstructions were encountered by the drills, such as large cobblestones and bowlders, and more forcible measures had to be resorted to in order to pass them. When that

was the case the drill rods were removed from the casing and one-half to two sticks of 40 per cent Atlas powder were lowered into the hole, having previously been connected with a battery on the scow.

The casing was then hoisted from 4 to 6 feet above the bottom of the hole and the powder exploded. This plan would generally remove the obstruction and the work could be continued until another bowlder was met with.

In some of the bore holes between Troy and Albany it would require from ten to thirty shots to advance below the depth of excavation necessary for a 30-foot channel, or to the surface of bed rock.

Samples were taken when the flow through the casing indicated that a different stratum was encountered, or when it was considered necessary.

The total number of samples collected is 348.

The rock found in the Hudson River is a hard shale and dark in color, and in nearly every case when this rock was encountered small fragments would be forced through the casing; or, if the flow after shooting was lost, small pieces or fragments of the rock would be brought to the surface on the end of the drill.

## PLOTTING.

All notes were plotted in the field office as the work progressed. The scale of the maps was 1: 5000. On the completion of the field work, a force sufficient to estimate the work necessary to provide 21 and 30 foot channels was transferred to Detroit.

## ALIGNMENT.

In locating the center line of the proposed channel it was the object to confine it as close as possible within the channel line as it now exists, to avoid heavy rock cutting, whenever possible, and limit the degree of curvature.

Following is a tabulated statement of alignment, including total length of curves and tangents, total curvature and maximum degree of curvature:

| Length. | | Maximum degree of curvature. | Total curvature. |
|---|---|---|---|
| Curve. | Tangent. | | |
| *Feet.* | *Feet.* | ° ′ | ° ′ |
| 69,523 | 144,982 | 1 16 | 485 50 |

## WIDTH OF CHANNELS.

The proposed width of the channel upon which these estimates are based is as follows:

| | Feet. |
|---|---|
| From station 5241+18 to station 5539+40 | 300 |
| From station 5539+40 to station 5905+80 | 400 |
| From station 5905+80 to station 7169 (end) | 600 |

CROSS SECTION.

The cross sections are of the standard form adopted by your Board for river improvement. The side slopes in rock cuts are 10 on 1 and in earth cuts 1 on 2.

BRIDGES.

The river between the State dam at Troy, N. Y., and the ocean is obstructed by six bridges.

DESCRIPTION OF BRIDGES.

| | Draw-span. | Width in clear in each draw. | Height of bottom chord above mean high water. |
|---|---|---|---|
| | *Ft. in.* | *Ft. in.* | *Ft. in.* |
| (*a*) Delaware and Hudson Railroad bridge at Bridge avenue, Troy, N. Y | 198 6 | 61 6 | 23 6 |
| (*b*) Congress street bridge, Troy, N. Y | 258 0 | 104 0 | 29 6 |
| (*c*) New York Central and Hudson River Railroad, upper bridge, Albany, N. Y | 275 0 | 110 7 | 33 5 |
| (*d*) New York Central and Hudson River Railroad passenger bridge, Albany, N. Y. *a* | 275 0 | 115 4 | 28 1 |
| (*e*) Lower bridge, or Greenbush bridge, Albany, N. Y | 400 0 | 169 8 | 22 7 |
| (*f*) Poughkeepsie bridge at Poughkeepsie, N. Y | | | 160 0 |

*a* Since this report was written this bridge has been replaced by a new one.

(*a*) Railroad, wagon, and passenger bridge. Built of iron, on stone piers, drawpier on land at east shore. The only opening through which boats ply in 36 feet 6 inches in clear from dock line, east shore. The draw is opened by steam power. There are four piers in the main channel of the river east of Starbucks Island, the respective widths in clear between piers being 170 feet 6 inches, 173 feet 6 inches, 173 feet 6 inches, and 160 feet to east shore line of Starbucks Island. In channel of the river west shore line of Starbucks Island to first pier, 150 feet 5 inches; between first and second piers, 177 feet 5 inches, and from second pier to Green Island dock line, 68 feet 6 inches, making in all six piers in the river. The bridge stands at right angles to the direction of the stream. It was built in 1876 by the Delaware Bridge Company.

(*b*) A wagon and passenger bridge built of iron on stone piers, and slightly oblique to the direction of the stream, with double draw opened by hand power. There are two piers and the drawpier in the river. Width in clear from east pier to dock, 205 feet 3 inches; width in clear from west pier to West Troy shore line, 210 feet. Built in 1874.

(*c*) A railroad freight bridge, built of iron on stone piers, and at right angles to the direction of stream. It has a double draw, opened by steam power. There are four piers and drawpier in the river; respective widths in clear between bulkhead lines, 146, 170, and 170 feet, commencing at Columbia Pier dock line. Built in 1870.

(*d*) A railroad and passenger bridge, built of iron on stone piers, at right angles to the direction of the stream. It has a double draw, opened by steam power. There are four piers and a drawpier in the river; respective widths in clear, 146 feet 5 inches, 175 feet, 175 feet, and 119 feet, commencing at Columbia Pier dock line. Built in 1875.

(*e*) A wagon and passenger bridge, built of iron on stone piers, at right angles to the direction of the stream. It has a double draw, operated by steam power. There are two piers and drawpier in the river; width in clear from west pier to Quay street dock line, 186 feet 3 inches; width in clear from east pier to shore line pier, 236 feet 3 inches. Built in 1886.

(*f*) A railroad bridge on iron piers, with stone foundations, at right angles to the stream. There are five spans, but no drawspan. and four piers in the river. Respective lengths of spans, 548, 525, 546, 525, and 548 feet, cantilever type.

### DAM AT TROY, N. Y.

The legal height of crest of dam is 12.07 feet above mean low tide of Hudson River at Albany, N. Y.

Crest of dam is 8 feet below top of masonry of sloop lock.

The total length of weir is 1,100 feet.

### DEPOSIT OF WASTE MATERIAL.

Generally all material excavated will have to be deposited either on the shore or behind established lines, and so protected that during freshets it is not carried into the channel; or deposited in the river at such points as may be selected by the engineer in charge of the improvements. This matter can be decided upon, however, when the contemplated improvement is undertaken.

### CHARACTER OF MATERIALS TO BE EXCAVATED.

As previously stated, the rock on this division consists entirely of Hudson River shale and must be excavated under water.

From the Troy dam to station 5659+50 the material above the rock consists of bowlders, stones, sand, gravel, and some clay. Bowlders form nearly the entire covering of the rock for the first 6,000 feet below the dam. For the remainder of the distance to station 5659+50 the finer materials predominate.

From station 5659+50 to the end of the work the excavation above the rock will consist entirely of sand, fine gravel, and some clay, and can be readily handled by a pump dredge.

### QUANTITIES.

The following tables give the estimated quantities and cost for both the 30 and 21-foot channels. The quantities from the State dam to

the lower end of the approach to lock No. 12, station 5235, are included with those for the Hudson River division, Appendix No. 10.

THIRTY-FOOT CHANNEL.

[Troy to Albany, station 5235 to station 5659 + 50.]

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Excavation: | | | |
| Earth, wet ..... cubic yards.. | 762,117 | $0.30 | $228,635 |
| | 8,201,433 | .25 | 2,050,358 |
| Rock, wet ..... do... | 2,429,161 | 2.00 | 4,858,322 |
| Total ..... | | | 7,137,315 |

[Albany to junction with Normans Kill line, station 5659 + 50 to station 5757.]

| | | | |
|---|---|---|---|
| Excavation, earth, wet ..... cubic yards. | 3,439,411 | $0.15 | $515,912 |

[Junction with Normans Kill line to deep water, station 5757 to below Sycamore Point.]

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Earth, wet ..... cubic yards.. | 48,942,073 | $0.15 | $7,341,311 |
| Rock, wet ..... do.... | 945,896 | 2.00 | 1,891,792 |
| Dikes: | | | |
| Piles ..... linear feet.. | 886,667 | .15 | 133,000 |
| Pine ..... feet B. M.. | 494,400 | a30.00 | 14,832 |
| Iron ..... pounds.. | 261,208 | .03 | 7,836 |
| Stone fill ..... cubic yards.. | 67,660 | .75 | 50,745 |
| Total ..... | | | 9,439,516 |

SUMMARY.

| | |
|---|---|
| For Champlain route only: | |
| Troy to Albany ..... | $7,137,315 |
| Albany to Normans Kill ..... | 515,912 |
| Total ..... | 7,653,227 |
| Common to both Champlain and Oswego-Mohawk routes, Normans Kill to deep water. | 9,439,516 |

TWENTY-ONE FOOT CHANNEL.

[Troy to Albany, station 5235 to station 5659+50.]

| | Quantity. | Cost per unit. | Total. |
|---|---|---|---|
| Excavation: | | | |
| Earth, wet ..... cubic yards.. | 715,768 | $0.30 | $214,730 |
| | 4,697,864 | .25 | 1,174,466 |
| Rock, wet ..... do.... | 744,709 | 2.00 | 1,489,418 |
| Total ..... | | | 2,878,614 |

[Albany to junction with Normans Kill, station 5659+50 to station 5757.]

| | | | |
|---|---|---|---|
| Excavation, earth, wet ..... cubic yards.. | 1,920,318 | $0.15 | $288,048 |

[Junction with Normans Kill line to deep water, station 5757 to below Sycamore Point.]

| | | | |
|---|---|---|---|
| Excavation: | | | |
| Earth, wet ..... cubic yards.. | 22,353,773 | $0.15 | $3,353,066 |
| Rock, wet ..... do.... | 111,126 | 2.00 | 222,252 |
| Dikes: | | | |
| Piles ..... linear feet.. | 886,667 | .15 | 133,000 |
| Pine ..... feet B. M.. | 494,400 | a30.00 | 14,832 |
| Iron ..... pounds.. | 261,208 | .03 | 7,836 |
| Stone ..... cubic yards.. | 67,660 | .75 | 50,745 |
| Total ..... | | | 3,781,731 |

a Per 1,000 feet.

SUMMARY.

| | |
|---|---|
| For Champlain route only: | |
| Troy to Albany | $2,878,614 |
| Albany to Normans Kill | 288,048 |
| Total | 3,166,662 |
| Common to both Champlain and Oswego-Mohawk routes, Normans Kill to deep water | 3,781,731 |

In conclusion, I wish to acknowledge the faithful services performed by my assistants, among whom should be mentioned E. J. Thomas, instrumentman; A. L. Harris and A. N. Dunaway, draftsmen; A. W. Clark, recorder, and Paul Beer; also the many courtesies received from Mr. Frederick W. Orr, of Troy, and R. H. Talcott, United States assistant engineer at Albany, N. Y.

Respectfully submitted.

H. F. DOSE,
*Assistant Engineer.*

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